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Mineral Technology Transfer: Evaluation of the CANMET Pit Slope Project

BRIAN W. MACKENZIE
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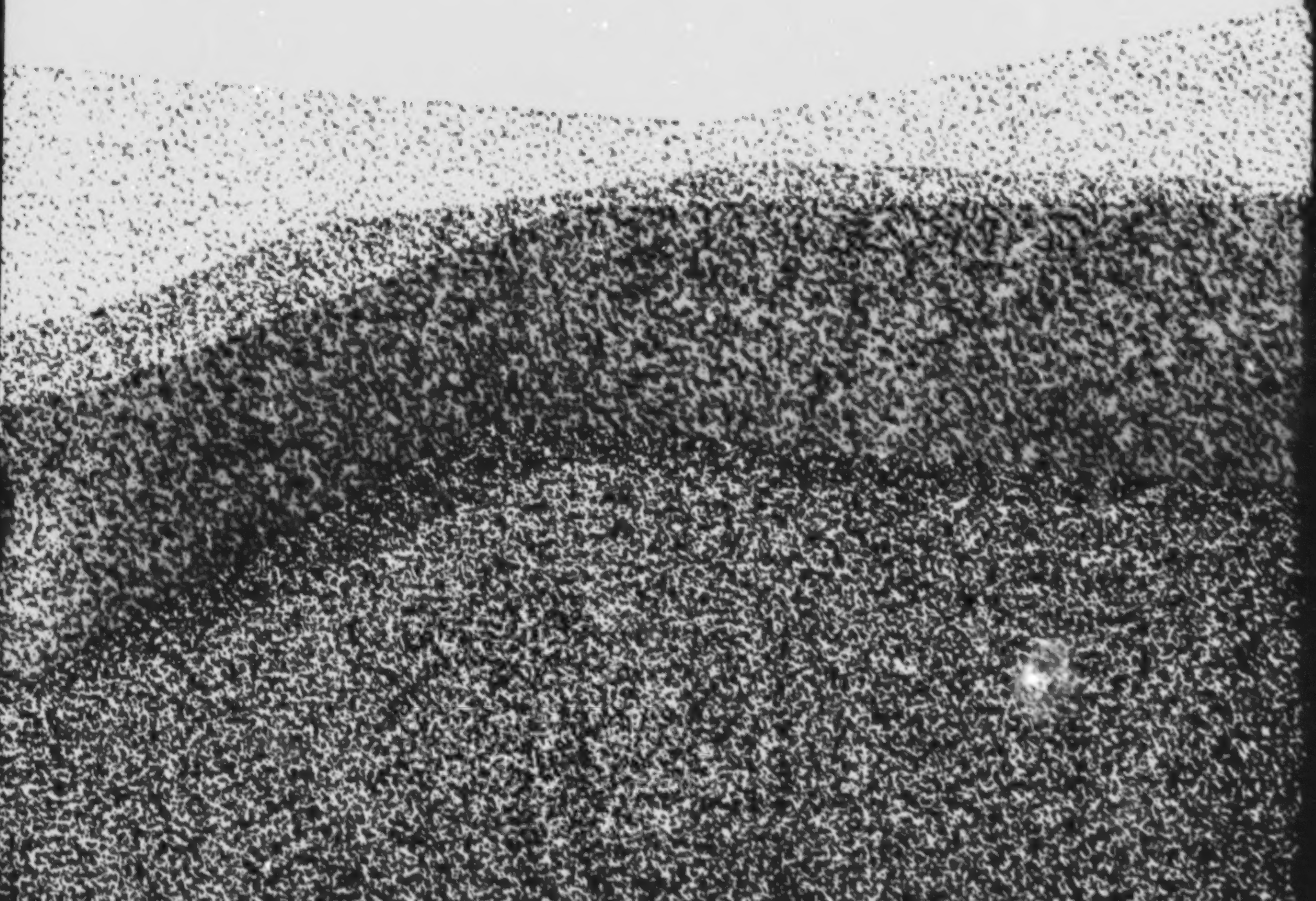

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by

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In memory of

Professor R.G.K. Morrison and Dr. D.F. Coates

former colleagues at McGill University
who shared a common interest in creating
awareness of the economic context for
technology change in mining

FOREWORD

This study was prepared under contract to the Canada Centre for Mineral and Energy Technology (CANMET). It represents independent research in the evaluation of a Canadian federal government program designed to assist the Canadian mining industry.

The views presented here are those of the authors and do not necessarily represent the views of CANMET, the Centre for Resource Studies, or its sponsors.

M.J. Wojciechowski
Centre for Resource Studies

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John Brennen and Suzanne Deschênes, Information Systems Division, Mineral Policy Sector, Energy, Mines and Resources Canada, provided useful statistics on ore and waste production from open pit mines.

Michel Bilodeau, Department of Mining and Metallurgical Engineering, McGill University, carried out the evaluation of pit slope advances in the nonferrous mining sector, conducted the risk analysis of the case studies, and directed the compilation and presentation of results, for all of which we are very grateful.

A number of reviewers, most notably C.O. Brawner, Peter Calder, David Henderson, and Evert Hoek, read an earlier draft of the manuscript and made helpful comments which are gratefully acknowledged.

Finally, we would like to thank André Potworowski and David Gladwin of CANMET who provided useful advice and constructive comments during the course of the study.

SUMMARY

A remarkable wave of advances in the engineering of pit slopes has been sweeping across surface mining in Canada during the past decade. The CANMET pit slope project is part of that wave. The objective of this study is to assess, quantitatively where possible, the costs, benefits and technical merit of the CANMET pit slope project.

The CANMET project, initiated in 1972, was based on a recognition of the importance of open pit mining in Canada and the potential, by improving slope design procedures, to excavate pit walls closer to their optimum angles. It was anticipated that this improvement would lead to substantial benefits from reduced waste excavation and increased ore recovery.

The goal of the project was to prepare an engineering manual for the design of open pit slopes and to transfer this technology to mining industry practice. The research and development phase of the project was carried out during the 1972-77 period. The Pit Slope Manual, published in 1977, was intended to be a practical working tool for the use of open pit mine operators. The period 1977-81, following publication of the manual, was set aside for technology transfer.

The cost of the CANMET pit slope project totalled $15.3 million, valued in constant 1980 dollars at 1982.[1]

At the outset of our study, 164 contacts were identified relating to use of the pit slope project and manual, divided into six interest groups: mine developers and operators, geotechnical consultants, university-based engineers, mine inspectors, open pit suppliers, and construction-based civil engineers. These contacts were our primary source of information for the study.

Within this framework, attention is focused on the largest Canadian open pit mining operations. Consequently, 23 mines were visited[2] and 42 interviews conducted. The other contacts were approached by letter and questionnaire. Overall, 58 percent of the identified contacts responded to our request for information. A 71-percent response was achieved for

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1. The current dollar cost of the project, $4.8 million, is converted to constant 1980 dollars, the standard used in our study. An 8-percent discount rate, our best estimate of the cost of capital which typifies investment in the mining sector, is then applied to bring the time distribution of project costs to 1982, the point in time selected for comparison of project costs and benefits.
2. These mines account for more than 80 percent of open pit metallic mineral and asbestos production in Canada, the main area of application for the CANMET project.

mine operators and geotechnical consultants, the two interest groups of most importance to the study.

Mine visits and interviews yielded 20 quantifiable cases of actual technological advances at established Canadian mining operations which have realized benefits attributable in part to the CANMET pit slope project. In view of the imprecisions which are an integral part of the interview process, we have endeavoured to treat the interview results in a conservative manner. For each case, a retrospective assessement of direct benefits is carried out in three stages. The present value of cash flows resulting from the 20 cases is estimated to be $232 million. The most-likely present value of cash flows attributable to the actual advances, after allowing for the opportunity cost of making these changes in the future without benefit of the CANMET project, totals $169 million. Finally, the most-likely present value of cash flows attributable to the CANMET pit slope project itself is assessed at $41 million.[3]

A risk analysis of the benefits associated with these 20 actual cases has also been conducted. Results give a 90-percent assurance that the attributable benefits are between $33 million and $46 million. Furthermore, based on the risk profile assessed, it is virtually certain that the benefit attributable to the CANMET project from these 20 cases at least equals its $15.3 million cost.

Documentation of seven similar cases which could not be fully evaluated, an awareness that mining industry benefits are mainly restricted to metal mines, and a broader assessment of benefits for the nonferrous mining sector, provide bases for scaling up the case study evaluation to the mining industry level. We conservatively estimate that the direct benefits attributable to the CANMET pit slope project which have been realized at Canadian open pit mining operations are 50 percent higher than the most-likely benefit for the 20 cases, or $61.5 million.[4] Thus, the quantifiable benefit-cost ratio associated with the CANMET pit slope project is estimated to be 61.5/15.3 = 4.0. We have reconciled these actual results with those anticipated in the original justification of the CANMET pit slope project.

While the precise numbers are uncertain and debatable, their general magnitude gives a convincing message. Even considering only the twenty specific case studies, the benefits at least equal the cost of the project. Whether these benefits then scale up to a three-, four-, or five-to-one ratio is not very important. At a minimum, the CANMET pit slope project has paid for itself.

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[3] As with project costs, these benefits are expressed in 1980 dollars at 1982.

[4] Given current Canadian mining taxation conditions, a tax rate of 43 percent would most likely apply to this benefit. Thus, about $35 million of the total would be realized by the mining companies concerned in enhanced after-tax cash flows, and about $26.5 million would be collected by federal and provincial governments as increased tax revenues. In this way, governments indirectly benefit from the project.

Around the quantifiable core benefit of $61.5 million, a broader sphere of less tangible benefits attributable to the CANMET project has been documented.

1. Creation of a general awareness in mine design, planning, operation, and management that pit slopes can be rationally designed and controlled through the application of engineering principles. In our judgment, this is the most important single benefit of the CANMET project.

2. Generation of indirect benefits in terms of indirect mining cost savings, the multiplier effect of mining benefits elsewhere in the Canadian economy, and enhanced employment, foreign exchange earnings, and regional development opportunities.

3. Improvement in the design characteristics of new open pit mine developments, and the resulting positive effects on the economics of long-term mineral supply in Canada.

4. Contribution to positive changes in government mining regulations, and the interpretation and administration of regulations.

5. Contribution to the development of geotechnical consulting capability in Canada, primarily arising from the contracting-out process used in the research and development phase, and from the increased demand for consulting services created at open pit mines.

6. Improvement in the standard of education for students in mining and geological engineering programs at Canadian universities resulting from their exposure to the engineering design and operating practices embodied in the Pit Slope Manual.

7. General feeling of mine operators, government regulators, unions, and consultants that the CANMET project has had a positive effect on achieving safer working conditions in open pit mines.

8. Benefits realized outside of Canada from application of the Pit Slope Manual, particularly in the United States, South Africa, Australia and the United Kingdom.

In other areas examined, the benefits associated with the CANMET project appear to be very restricted. These areas include nonmetallic mineral, structural material, coal, and tar sands mining operations, open pit suppliers, and civil engineering construction.

Despite the remarkable advances in pit slope technology which have taken place during the past decade, evidence indicates that there are important potential benefits yet to be realized. Case study results show that the time stream of benefits attributable to the CANMET project has declined only modestly with time. About 20 percent of the nonferrous mining operations visited and interviewed are judged to have major improvement potential, based on present slope engineering procedures. There appear to be more widespread opportunities for technological advances in iron ore and coal mining.

The following summary evaluation of the CANMET project, manual, and technology transfer mechanisms is generalized from a large number and wide range of interview and questionnaire responses.

1. The CANMET project was well conceived in both technical and economic terms. The evidence assembled in this study leaves little doubt that it was the single most worthwhile mineral research and development project for Canada to undertake in the 1970s.

2. In retrospect, the mining industry should have been more fully involved in the formulation, implementation, and management of the project. This would have encouraged the participation of more mines in the research and development phase, and helped tailor the manual more closely to the needs of mine operators.

3. The contracting-out process adopted for the CANMET project proved to be a valuable mechanism for the transfer of technology. However, benefits would likely have been considerably improved by a more even balance among organizational inputs - more contact of CANMET staff with mine operators, greater involvement of mine operators in the contracting out process, more CANMET input into coordinating the technical work, and less emphasis on geotechnical consultants.

4. Problems were encountered in coordinating and integrating the research and development phase due to the broad project scope and the contracting-out approach adopted. There is a general feeling that the cost of the project was too high for the work which was actually performed.

5. The probabilistic 'reliability analysis' philosophy which underlies the CANMET project is conceptually and analytically enlightened. However, the presentation of this philosophy in the Pit Slope Manual is strongly criticized as being unnecessarily complex and academic, and has seriously detracted from the value of the manual. The design philosophy should have been introduced as a logical extension of the traditional factor-of-safety approach to pit slope design. Both approaches, it is suggested, should have been included. This aspect of the project has worked against the manual's purpose of providing a practical working tool for mine operators.

6. There was a definite need for the Pit Slope Manual at the time of its publication and there still is. Although the manual includes little in the way of new or unique knowledge, by integrating relevant existing technologies related to pit slope engineering, it has made a significant contribution to the state of the art for pit slope design and control in Canada. The manual provides a means for mine operators in remote locations, not necessarily familiar with rock mechanics, to understand pit slope problems and opportunities and how to deal with them. Thus, the manual represents new knowledge in the hands of these users.

7. General views and our case study assessments both indicate that the majority of CANMET project benefits have been derived directly from the research and development phase, completed in 1977, rather than from the Pit Slope Manual. This finding reflects in part the high potential for improvement associated with the mining operations considered in the research and development phase. These project-related benefits resulted mainly from the direct participation of mining companies in the project and from the involvement of CANMET personnel at these operations. This reinforces the critique concerning the balance of research and development effort given under point 3. There is also a widely-held impression that the benefits realized from the manual have been disappointing.

8. The Pit Slope Manual reflects state-of-the-art technology circa 1975. Thus, there are opportunity costs associated with the manual's use in 1983 and beyond. If the manual is to play a future role in Canadian pit slope design, it needs to be selectively revised, updated and extended. Regarding possible extension of the manual, the two areas of greatest interest and hightest potential appear to be: inclusion of detailed case studies with practical solutions, and attention to slope stability concerns for coal mine operators, particularly in western Canada.

9. The prevailing view is that the Pit Slope Manual transfers technology to open pit mining practice cheaply and extensively. However, it is only one element of the technology transfer process. There is also a critical need for more intensive on-going mechanisms. In this regard, practical problems seem to have arisen when the research and development phase was completed and the project team disbanded. A few seminars were conducted at the beginning of the 1977-81 technology transfer phase. There is a strong correlation between the engineering personnel and mining operations represented at these seminars and the manual-related benefits realized. Unfortunately, the technology transfer effort appears to have ended in 1978. This has been a serious impedement to the realization of potential project benefits.

10. The general feeling expressed in comments received is that the technology transfer phase should have included all of the following elements on a modest but on-going basis:
    - seminars and training programs;
    - selected mine visits by CANMET personnel;
    - availability of a resource person at CANMET for mine operators to contact for advice;
    - updating, revision, and extension of the manual.

    Personal contact is essential to the transfer of technology. There is a critical need for more contact by CANMET personnel in the real world of Canadian mining operations.

In light of our study findings, we recommend that consideration be given to reinstituting the technology transfer phase of the CANMET projet abandoned in 1978. This new thrust could evolve from the revisions of the Pit Slope Manual which are apparently already in progress. It is vital that the technology transfer program be comprehensive, embodying all four elements cited in point 10 above.

There is a general awareness arising from this study that advances in pit slope technology, particularly the more important ones, require a rather improbable combination of circumstances: initiative and awareness of engineering staff regarding the potential for improvement; concepts and confidence to implement change arising from the advice of consultants and government experts; and communications, justification, and support from mine management. Mineral technology transfer and application is certainly not a fast, continuous, pervasive process. Rather, it occurs once in a while when a set of unusually favourable circumstances combine. Futhermore, as our case studies illustrate, it often takes several years to bring an opportunity for technological advance to the point of implementation.

There are important lessons to be learned from the CANMET pit slope project. These should help provide an improved basis for directing mining research and development funds along lines which are most beneficial to the productive capability and competitiveness of the mineral sector in Canada. The pit slope project experience should also help establish guidelines for planning future government-industry research initiatives.

Despite the practical limitations of the CANMET pit slope project, this study confirms its technical and economic merits. The project has made an important contribution to the difficult process of mineral technology transfer. The bottom line is that, in retrospect, the CANMET pit slope project is economically justified for the federal government, the mining industry, and Canadian society.

Finally, the economic and technical assessment conducted here clearly demonstrates the considerable amount of effort which is required to carry out an evaluation of the effectiveness of a research and development project.

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1. INTRODUCTION

Study Setting

Canada is the world's third largest mineral producer and the largest exporter of mineral commodities. The Canadian mineral industry is highly diversified, both geographically and in terms of product mix. Our present mineral capability yields an annual value of production (in 1984, excluding oil and gas) in the order of $15 billion.

The Canadian mineral industry has achieved a high growth rate during the past 20 years. Essentially all of this growth has been associated with open pit mining, which currently accounts for more than 80 percent of ore production. These developments have been supported by remarkable advances in open pit mining technology. Canada has been a leader in this field.

The mineral sector has been the subject of increasing concern during the 1980s. The federal government's November 1981 budget paper, Economic Development for Canada in the 1980s, gives prominence to natural resources, including minerals, as the leading opportunity for national economic development. In March 1982, Energy, Mines and Resources Canada released Mineral Policy: A Discussion Paper. This policy document describes key factors and issues impinging on the mineral industry, establishes priority areas for attention, and recommends policy initiatives within each priority area. At the same time, the Canadian mineral industry has been experiencing a deep and prolonged recession. After absorbing substantial losses in 1982-83, net income for the industry (excluding energy) totalled $210 million in the first half of 1984, a marked improvement over 1983 but nowhere near pre-recession levels.[5] Despite predictions of improvement, mineral commodity prices have remained generally weak on world markets and demand has continued to be sluggish. Mineral policy, at both federal and provincial levels, will have a crucial effect on the ability of the mineral industry to recover from present adversity and respond to the challenge of continuing its key role in Canadian economic development.

The Canadian mineral industry produces and sells in a competitive international marketplace. Our present and future prospects are controlled by market supply and demand conditions, the most fundamental being the economic health of our customers, the industrialized nations. Within this fundamental demand constraint, the key factor is Canada's competitive position as a mineral supplier in league with other major mineral producers. Fortunately, this key factor is in part controllable.

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[5] G.O. Vaugh, 'Mineral Industry: Review and Outlook', Canadian Mining Journal, February 1985.

Canada's competitive position in international mineral markets depends on the productivity and cost effectiveness of our mineral industry. One of the main ways of strengthening this position is through technological advances realized from successful mineral research and development. This explains why mineral research and development should be a vital policy issue both in mining companies and in government agencies responsible for the mineral sector.

CANMET

The Canada Centre for Mineral and Energy Technology (CANMET), a branch of the Department of Energy, Mines and Resources, is engaged in a wide range of studies which focus on the safer and more efficient extraction, processing and use of the country's mineral and energy resources.

The work of CANMET includes basic and applied research, development, demonstration and, finally, technology transfer. CANMET's problem solving lies in three distinct but related fields: explosives technology, minerals technology, and energy technology. The staff consists of about 700 scientists, engineers, technicians and other support staff. The 1981 operating budget was about $33 million. Approximately $6 million of this budget went into research and development contracts conducted by private industry and universities.[6]

The CANMET Pit Slope Project

The CANMET pit slope project, initiated in 1972, was based on a recognition of the importance of open pit mining to the Canadian mineral industry, and of the potential for excavating pit walls closer to their optimum angles by improving slope design procedures. It was anticipated that this improvement could lead to substantial benefits, either from reduced waste excavation or from increased ore recovery.

The goal of the pit slope project was to prepare an engineering manual for the geotechnical design of open pit slopes. Design specifications for waste embankments (particularly tailings dams), and environmental factors of concern in mine planning were also included in the scope of work. The Pit Slope Manual, published in 1977, was intended to be a practical working tool for the use of open pit mine operators.[7]

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6. Mineral Policy: a Discussion Paper; Energy, Mines and Resources Canada, December 1981, p. 126.
7. Pit Slope Manual, ten chapters with supplements, 27 volumes, CANMET; Energy, Mines and Resources Canada, Ottawa, 1976 and 1977.

The project embodied elements of applied research, synthesis of existing knowledge, development, field demonstration, and technology transfer. The research and development phase was carried out during the 1972-77 period. The period 1977-81, following publication of the manual, was set aside for technology transfer, to assist engineers and planners in adapting the procedures described in the manual. This need was addressed by a series of workshops for mine staff.

The importance of support from the mining industry, geotechnical consultants, and universities was recognized from the beginning of the project. Accordingly, the project took the form of a cooperative venture, financed by industry and the federal government. Most of the research and development work was contracted to 42 outside organizations.

The CANMET pit slope project represents a very important case study for mineral policy analysis for a number of reasons:

- the attention given to cost-benefit justification of the project in the planning stage;
- the focus on productivity improvement for open pit mines;
- the project's magnitude - the largest single mining research and development project ever carried out in Canada;
- the heavy reliance placed on contracting out the research and development work;
- the partnership of industry and government in joint venture financing;
- the emphasis placed on producing a working manual, technology transfer, and practical application.

What lessons can we learn from this experience for planning and implementing future mining research and development projects?

Objective and Scope of Study

The objective of our study is to assess, quantitatively where possible, the costs, benefits, and technical merit of the CANMET pit slope project.

We hope the study will help provide an improved basis for directing mineral research and development funds along lines which are most beneficial to the mining industry, and for planning future government-industry research inititiaves.

The scope of work is as follows:

- identify users and potential users of the pit slope manual as well as other relevant interest groups;

- prepare a framework for assembling the information required for the study and survey the relevant interest groups accordingly;
- assess the technical merits of the pit slope project;
- review the need for the pit slope manual and determine if it is an appropriate vehicle for technology transfer;
- identify and quantify any direct benefits and costs which resulted from the contracting-out process used;
- carry out a cost-benefit analysis of the project.

Within this framework, attention is focused on the 20-25 largest Canadian open pit mining operations.[8] Detailed profiles are developed for each of these mines through on-site visits and interviews. These form the basis for case study assessment of benefits attributable to the CANMET pit slope project.

Organization of Study

The sources and assembly of information for the study are outlined in chapter 2.

Chapter 3 describes the historical evolution and present role of open pit mining in Canada; outlines the open pit mining method; illustrates the potential economic effects of steepening pit slope angles; and provides an overview of the literature on pit slope technology.

The CANMET pit slope project is introduced in chapter 4, describing its original justification, the implementation and content of the project, a summary of the Pit Slope Manual, and an assessment of project costs.

The assessment of direct benefits attributable to the CANMET pit slope project at established Canadian open pit mining operations, based on 20 actual case studies, is described in chapter 5 and, on this basis, a benefit-cost ratio for the project is determined.

Chapter 6 discusses the broader sphere of less-tangible benefits attributable to the CANMET pit slope project.

Finally, a more specific critique of the pit slope project, manual, and technology transfer mechanisms is provided in chapter 7.

Several matters discussed in the text are developed in greater detail in the appendices.

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[8] The 23 mines actually visited in the course of the study account for more than 80 percent of open pit metallic mineral and asbestos production in Canada, the main areas of application for the CANMET project.

2. ASSEMBLY OF STUDY INFORMATION

Information required for study purposes has been derived from a wide range of sources.

Statistics relating to the historical evolution and present role of open pit mining in Canada have been provided by the Information Systems Division, Mineral Policy Sector, Energy, Mines and Resources Canada. These data are presented in summary form in chapter 3.

A review of the literature on open pit slope stability has been conducted. Findings relevant to the study are summarized in chapter 3.

Documentation concerning the CANMET pit slope project itself, as outlined in chapter 4, was obtained from CANMET files on the subject and from a draft technical and financial summary report provided by CANMET at the start of our study.[9]

A nonferrous deposit-specific data base and methodology which has been developed at the Centre for Resource Studies is used in chapter 5 to help scale up the benefits evaluated for 20 actual case studies to the mining industry level. This source of information and the assessments carried out are described in appendix V.

At the beginning of our study, a list of contacts was compiled regarding use of the CANMET pit slope project and manual. This list was our main focus of attention for the assembly of information. The contacts made have been divided into six interest groups, as shown in table 1.

Table 1

IDENTIFIED CONTACTS CONCERNING USE OF CANMET PIT SLOPE PROJECT AND MANUAL

Interest Group	Number of Contacts
Mine developers and operators	56
Geotechnical consultants	28
University-based engineers	38
Mine inspectors	11
Open pit suppliers	24
Construction-based civil engineers	7
Total	164

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[9] Technical and Financial Summary Report on the CANMET Pit Slope Project, 1972-1982, M. Gyenge and J. Palmer, confidential draft report, 82/03/05.

In May and June 1982, a letter was sent to each contact advising of the study, outlining terms of reference, soliciting views on particular areas of concern, and asking for suggestions of case studies which should be documented. Where appropriate, requests were made for mine visits or interviews.

Also in May, a presentation was made at the Canadian Rock Mechanics Symposium in Vancouver, providing symposium participants with the study background, objectives, and plan for information assembly and analysis, and requesting their support.

As a basis for mine visits and interviews with open pit operators, a checklist of information required was prepared as given in appendix I. The main elements for this compilation of information are as follows:

- development of open pit operating profiles for the period 1972-81;
- documentation of major changes in pit design, planning and operation which have occurred during this period;
- where appropriate, case study description of changes which are at least in part attributable to the CANMET pit slope project;
- commentary on experience with and views on the Pit Slope Manual.

Similarly, an information checklist for interviews with geotechnical consultants was prepared (appendix I), the main elements being as follows:

- general views concerning the effect of the CANMET pit slope project on open pit mine design and civil engineering construction;
- growth of consultancy during 1972-81 period, including international business expansion, possible involvement with the pit slope project, and any effect of the project on consulting activities;
- documentation of rock slope problems encountered, and possible effects of the CANMET pit slope project on their solution;
- commentary on experience with and views on the Pit Slope Manual.

In July 1982, a follow-up letter was sent to those contacts whom we did not intend to visit or interview. A questionnaire, specific to each type of contact or interest group, was attached. The questionnaires are included in appendix II. The intention was to keep this request for information to a minimum but to leave the door open for a subsequent interview if warranted.

Interviews began in mid-May and mine visits commenced in early June, scheduled for completion by mid-July. The unprecedented number of mine shutdowns which occurred during this period delayed the study schedule by about one month. Details of mine visits made and interviews conducted are given in appendix III.

Generally, the response to our request for mine visits and interviews was very good and our reception excellent, particularly in view of the severe financial and personnel constraints within which the mining industry was operating at the time. As a result, a wealth of information has been assembled for analysis.

With reference to the interview checklists given in appendix I, the following comments summarize the results of the interviews conducted:

i information relating to the development of pit profiles for the mines visited was readily available;

ii a wide range of commentary, opinions and ideas on the CANMET pit slope project and manual were obtained. These views are discussed in chapters 6 and 7;

iii the case study documentation of advances in pit slope technology, including the attribution of benefits to the pit slope project, was particularly difficult and usually required follow-up discussions.[10] Results are presented in chapter 5;

iv while geotechnical consultants were generous in providing general views on advances in pit slope technology, and on the CANMET project and manual, they were very reluctant to discuss their particular experiences in solving rock slope problems.

The response to our written requests for information, as might be expected, was poor. Only 32 percent of those contacted in this manner replied. Nevertheless, a number of detailed and thoughtful submissions have been received. These are considered in chapters 6 and 7.

A tabulation of the number of contacts actually made during the study by form of contact and by interest group is presented in table 2. The response is 58 percent overall, and 71 percent for mine operators and geotechnical consultants, the two interest groups which are of most direct importance to the study.

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[10] The difficulty encountered here is one which commonly arises when engineers and geologists are asked to provide subjective quantitative estimates about uncertain events and outcomes. Obtaining meaningful estimates in this regard requires particular attention and perseverance which, in this instance, has yielded 20 case studies.

Table 2

NUMBER OF STUDY CONTACTS

	Form of Contact				
Interest Group	Mine Visits	Inter-views	Written Responses	Number of Contacts[a]	Overall Response[b] (percent)
Mine developers and operators	22	16	4	40	71
Geotechnical consultants		12	8	20	71
University-based engineers		6	10	15	38
Mine inspectors		6	6	10	91
Open pit suppliers			7	7	32
Construction-based civil engineers		2	2	3	43
Total	22	42	37	95	58

[a] Contacts made using more than one form are counted only once.
[b] As a percentage of the number of identifed contacts given in table 1.

3. THE ROLE AND DEVELOPMENT OF OPEN PIT MINING IN CANADA

Historical Evolution and Present Role

Canada has a well-deserved international reputation for hardrock underground mining. Nevertheless, important open pit mines have operated from the earliest times at such centres as Asbestos, Sudbury, Kimberley, and Copper Mountain, and the mining of nonmetallic minerals and structural materials using surface methods has always been widespread. In the fifties, the tempo of open pit mining accelerated with the major expansion of the iron ore industry in eastern Canada.

The overall tonnage of ore mined in Canada almost tripled during the 1961-80 period, as illustrated in figure 1, to an annual rate of some

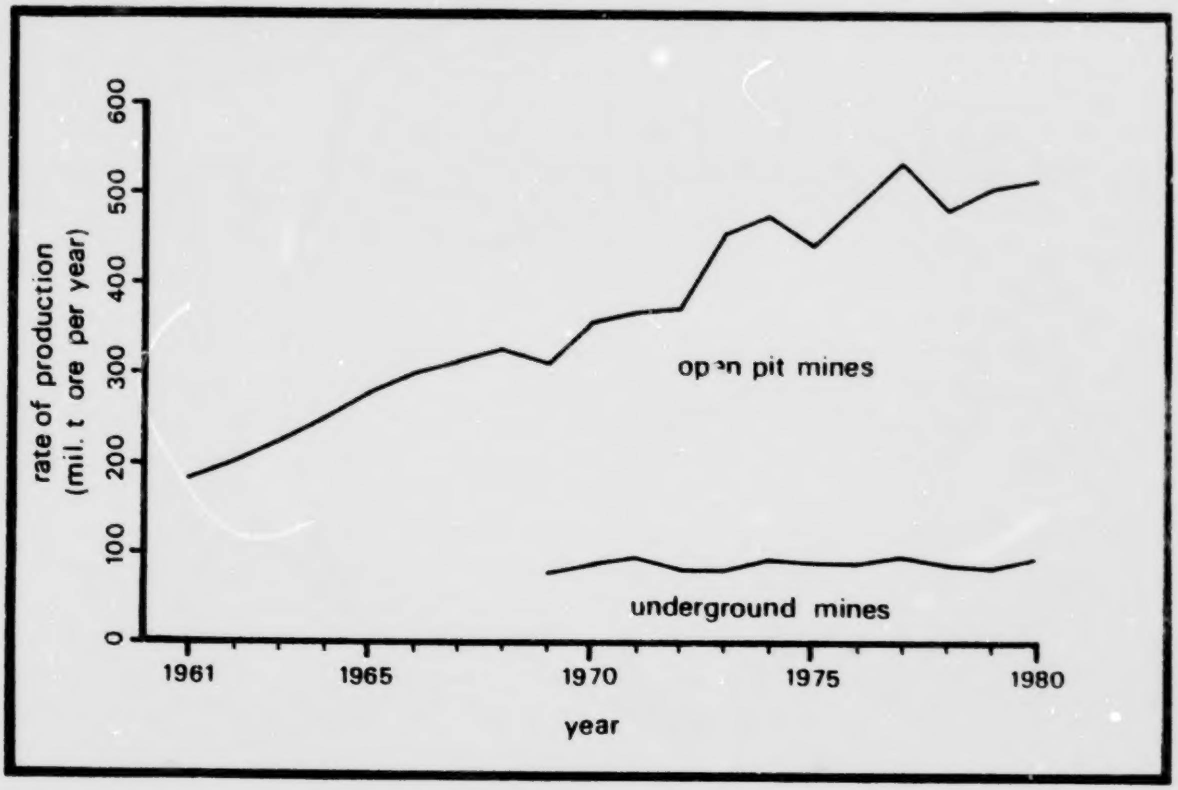

Figure 1. Rates of Ore Production, 1961-80

518 million tonnes in 1980. Ore production from underground mines remained more or less constant over this interval[11], its share of the total dropping from about half in 1961 to less than one fifth in 1980. Thus, essentially all of the growth in Canadian mining during this period was accounted for by open pit mining. The main elements of this remarkable record of growth in open pit ore production were the development of major copper and molybdenum mines in British Columbia, continued expansion of the iron ore sector, and surface coal mining developments, particularly in western Canada.[12]

Open pit mining presently accounts for 82 percent of Canada's ore production by volume.[13] The substantial increase in its relative importance during the 1961-80 period has resulted mainly from rising labour costs in underground mining coupled with important technological advances in the development of large-scale open pit equipment and in engineering practice for the design and control of open pit walls. While underground operations will no doubt continue to play an important role in mining higher grade nonferrous and precious metal deposits, and acknowledging that ore production from these sources makes a relatively larger contribution to value of production than to ore tonnage, it would be surprising if open pit mining did not continue to realize most of the growth in the Canadian mining industry, at least in the foreseeable future.

A breakdown of open pit ore production by commodity type is presented in figure 2. Metal mines accounted for about 55 percent of the total in 1980, and structural materials for 29 percent. The remainder was mainly distributed between coal mines (8 percent) and asbestos operations (6 percent). Coal's share can be expected to increase significantly during the 1980s. Within the metal mining sector, ore production is fairly evenly divided between iron ore mines (28 percent) and nonferrous metal mines (26 percent). The shares of value of production associated with open pit metal mines, and especially nonferrous metal mines, are significantly greater than their respective shares of 55 percent and 26 percent, determined on the basis of ore tonnage, particularly in relation to the structural materials mining component.

Removal of overburden and excavation of waste rock are necessary for open pit ore production.[14] The ratio of waste to ore mined (the

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[11] Underground mine production would have declined significantly except for the development of the Saskatchewan potash industry which had achieved a 27-million-tonne annual rate of production by 1980.

[12] Tar sands operations, of increasing importance, are not included in these trends.

[13] Unfortunately, no statistical breakdowns by value are available.

[14] Except possibly for massive deposits of structural materials.

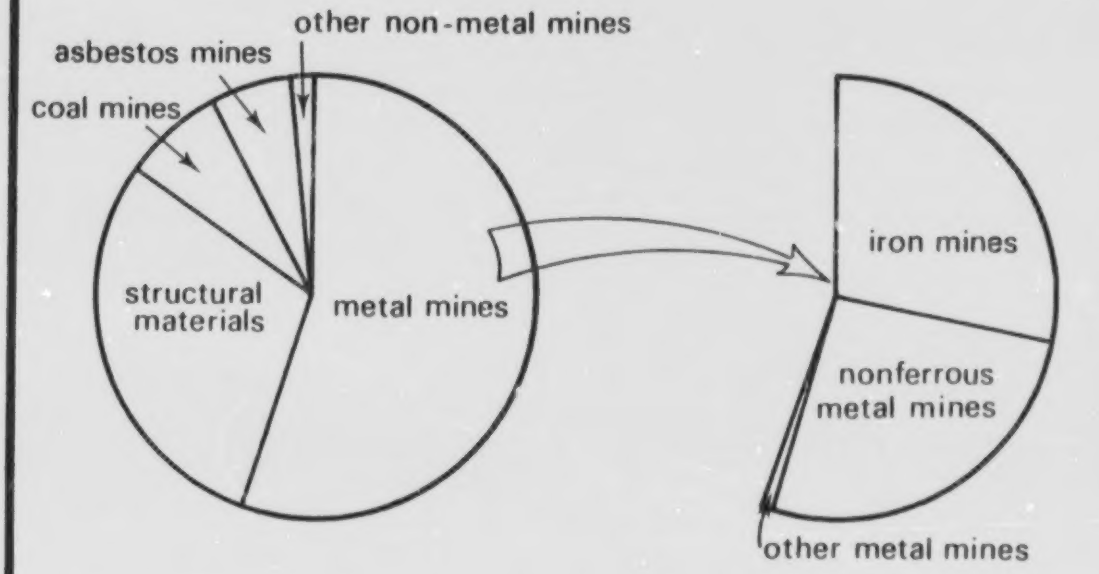

Figure 2. Open Pit Ore Production by Commodity Type, 1980

'stripping ratio') is a critical determinant of the cost effectiveness of open pit mining operations. The stripping ratio may be lowered (improved) by reducing the amount of waste excavated or by increasing the recovery of ore. The overall pit slope angle controls the stripping ratio which can be achieved in practice. As an open pit deepens, the amount of waste excavated per tonne of ore increases.

Average stripping ratio information for Canadian metal mines is presented in figure 3. In 1969, one tonne of waste was excavated on average for each tonne of ore mined. By 1980, the stripping ratio had increased to 1.3:1, due primarily to the increased depth of mine workings. For iron ore mines, an average of only 0.7 tonnes of waste is removed per tonne of ore mined, compared to an average stripping ratio of 2:1 for nonferrous metal mines. This in part reflects the relative values of these ores.

This brief outline of open pit mining in Canada serves to make the following points relevant to our study.

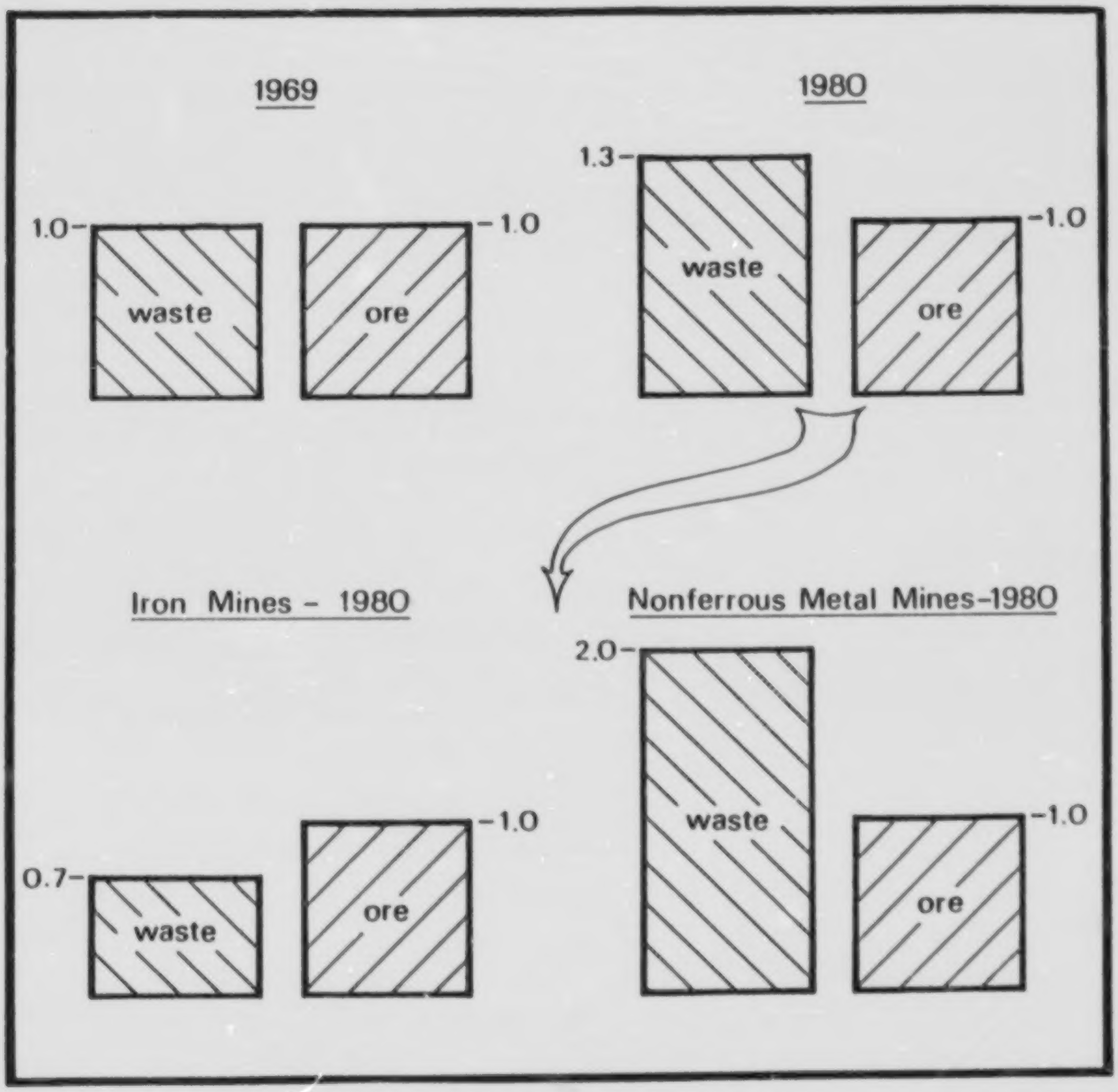

Figure 3. Average Stripping Ratios for Canadian Metal Mines

i Open pit mines have accounted for virtually all growth in the Canadian mining industry during the 1961-80 period, a situation which is expected to continue through the eighties.

ii The major share of open pit mine production is derived from metal mines, its two main components being nonferrous metal mines and iron mines. Iron mines produced slightly more ore in 1980, but nonferrous metal mines are more important in terms of value of production. Coal's share of open pit production will increase during the eighties.

iii The average stripping ratio for metal mines has increased by 30 percent from 1969 to 1980. In 1980, the average stripping ratio for nonferrous metal mines was almost three times as high as the ratio for iron mines.

The Open Pit Mining Method

A simplified description of open pit mining is included here for the non-technical reader.

The decision to develop and mine a mineral deposit is based on economic criteria. Whether a deposit should be mined by open pit or underground methods, or a combination of both, depends on relative costs. The main advantages of open pit mining are flexibility in production rate, safety, facility for selective mining and grade control, and low unit cost. The main disadvantage of the open pit method is that it requires the excavation of large quantities of waste rock. This waste material comes from overburden and from the sloping walls that have to be cut to enable excavation of the ore from pits presently planned to depths approaching 400 metres.

Thus, a key determinant of the economic viability of open pit mining is the quantity of overburden and waste which must be removed per tonne of ore mined, i.e. the stripping ratio. As illustrated in figure 4, the stripping ratio is determined in part by the geological configuration of the mineral deposit. It also depends on rock structure and technological considerations, factors which determine the maximum possible overall pit slope angle. Government mining regulations pertaining to bench design and the steepness of the pit slope also influence the stripping ratio which can be achieved.

Open pit mining consists of drilling, blasting, loading and haulage of overburden, waste rock, and ore. The excavation process proceeds in benches or levels from the surface down to an ultimate pit depth. This final depth may be determined by a geological limit, as for case D in figure 4. In other cases, for example cases A, B and C in figure 4, the ultimate pit depth reflects an economic limit for open pit mining which results from the fact that the stripping ratio, and hence the cost of waste rock removal, are functions of depth, as portrayed in figure 5. When the cost of excavating additional waste and ore equals the revenue from the additional ore, the ultimate pit depth is reached. If economic, underground mining methods would be utilized in these cases to extract the deeper ore.

Open pit mining is obviously a good deal more complex than this. Of interest to us here is the mining process which eventually results in the ultimate pit and the overall pit slope angle. These features are illustrated in figure 6.

The basic mining unit is the bench or level formed by a single production blast. The bench slope angle, a key determinant of the overall pit slope angle, is governed by rock structure, and by drilling and blasting technology. Bench height, like bench width, is dependent on the

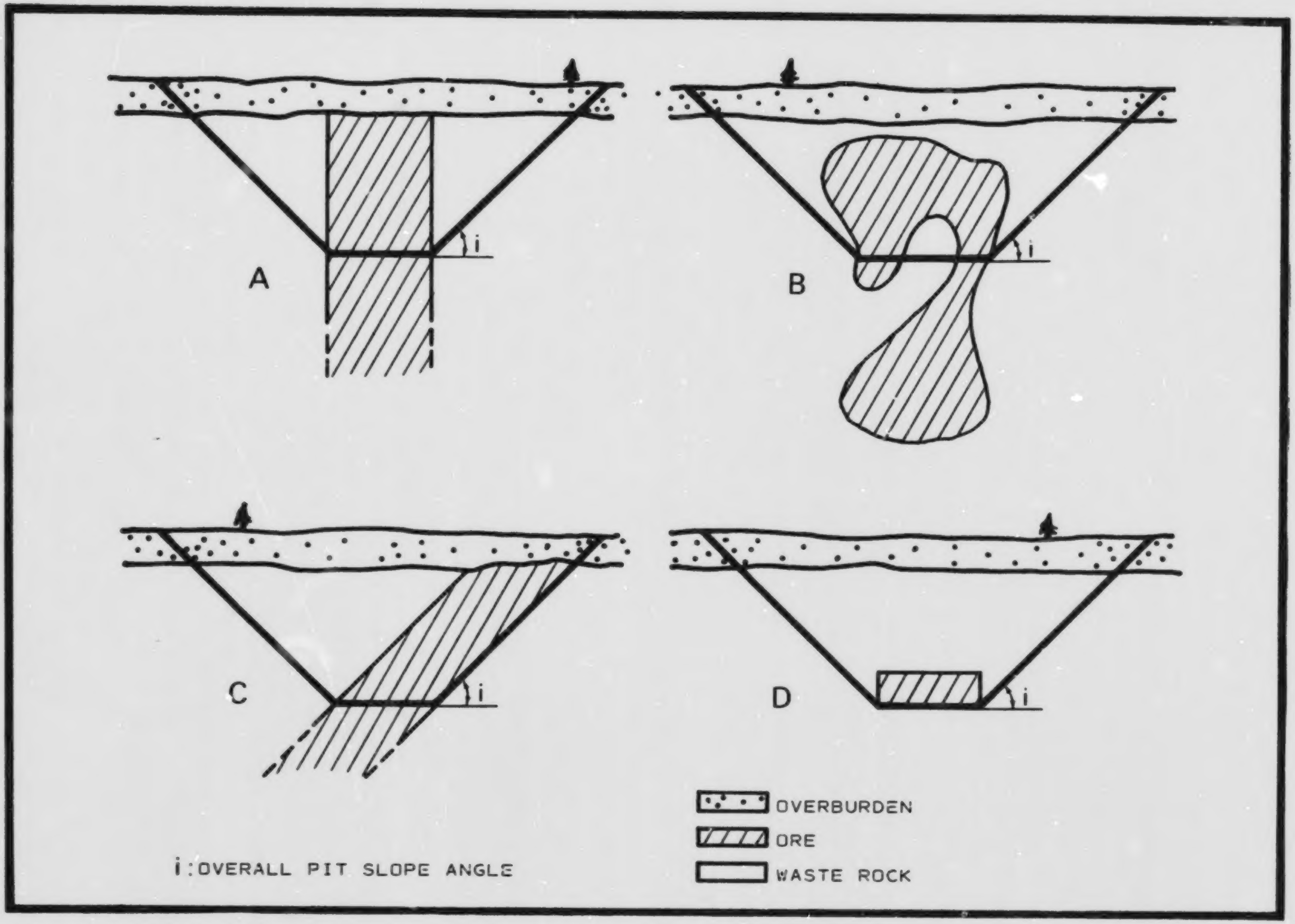
A
B
C
D
i
OVERBURDEN
ORE
WASTE ROCK
i :OVERALL PIT SLOPE ANGLE

Figure 4. Effect of Mineral Deposit Configuration on the Overall Stripping Ratio

size and reach of the open pit equipment used, but it is also designed with slope stability in mind.

To overcome the constraint of bench geometry on the overall slope angle, two or three benches are often combined into multiple benches (termed double or triple benching), as shown in figure 6. Berms, or catchment areas, are left on the pit face to control loose rock spalling from the face, and to provide access. Berms may be left every bench or every several benches depending on the mining practice. When a pit wall is being actively mined, the assemblage of benches and berms will form a distinct unit called a working slope. The working slope angle will be much flatter than the overall pit slope angle due to incorporation of the width of the active benches required for drills, shovels, and trucks. It is not necessary to maintain these benches when the ultimate pit wall is reached.

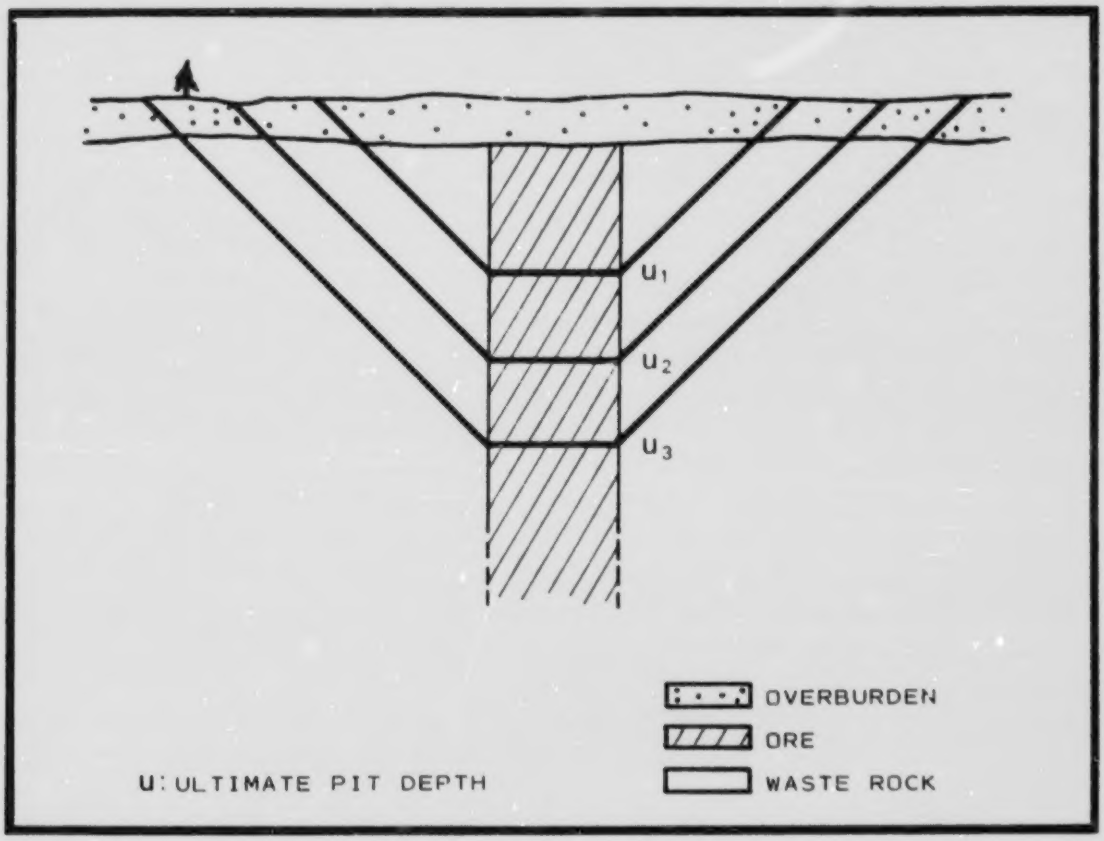

Figure 5. Effect of Ultimate Pit Depth on the Overall Stripping Ratio

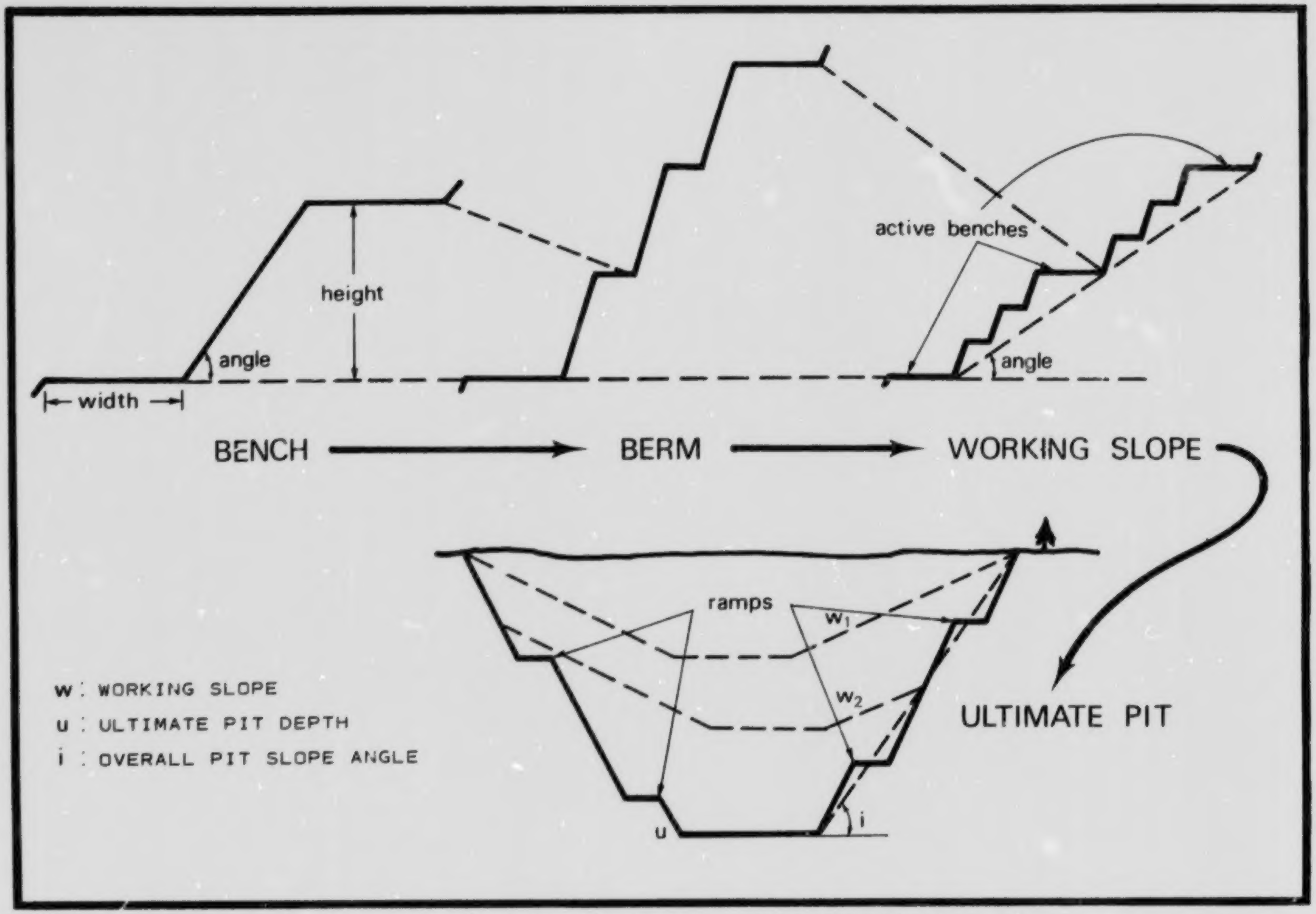
active benches
height
angle
width
angle
BENCH
BERM
WORKING SLOPE
ULTIMATE PIT
ramps
w_1
w_2
u
i
w : WORKING SLOPE
u : ULTIMATE PIT DEPTH
i : OVERALL PIT SLOPE ANGLE

Figure 6. The Open Pit Mining Method: Determinants of Overall Pit Slope Angle

The working faces are gradually pushed back towards the ultimate wall. Once the working slope reaches the final pit limit, the face is steepened to the final pit slope.[15] Steep walls usually require safety berms to catch loose rock. Ramps are carried on the pit walls, interconnecting the benches, for haulage purposes.

All of these features affect the overall slope angle of an open pit. This angle must be as steep as possible to minimize the overall stripping ratio. As depicted in figure 6, the overall pit slope angle is defined by a line from the toe to the crest of the ultimate pit.

Economic Effects of Steepening Pit Slope Angles

The economics of open pit mining is constrained by the overall pit slope angle which can be achieved. The steeper the slope that can be maintained with safety, the lower the volume which has to be excavated for a particular pit depth. Figure 4 suggests that this reduction in volume would largely be in waste rock. The significance of the associated decrease in mining cost depends on the deposit configuration.

The overall pit slope angle, as has already been noted, is a function of rock structure, the applied technology available, and safety considerations. The main objective of the CANMET project was to increase pit slope angles by advancing the application of technology to pit slope design and control, and to assist regulatory agencies in establishing slope design guidelines.

As illustrated in figure 7, if applied technology enables the overall pit slope angle to be increased while continuing to ensure safe working conditions, this improvement can be applied to enhance the economics of open pit mining in one of two basic ways:

i reduction in the amount of waste excavated and, hence, decrease in the average stripping ratio, as in case A, maintaining the same ultimate pit depth;
ii increase in the amount of recoverable ore reserves by deepening the ultimate pit, as in case B, while maintaining the same average stripping ratio.

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[15] A common practice is to sequence mining from higher to lower grade ores wherever possible, using very steep slopes in the early years of operation in order to maximize the return on investment. These slopes are then flattened during the intermediate development of the pit before being steepened to the final pit slope.

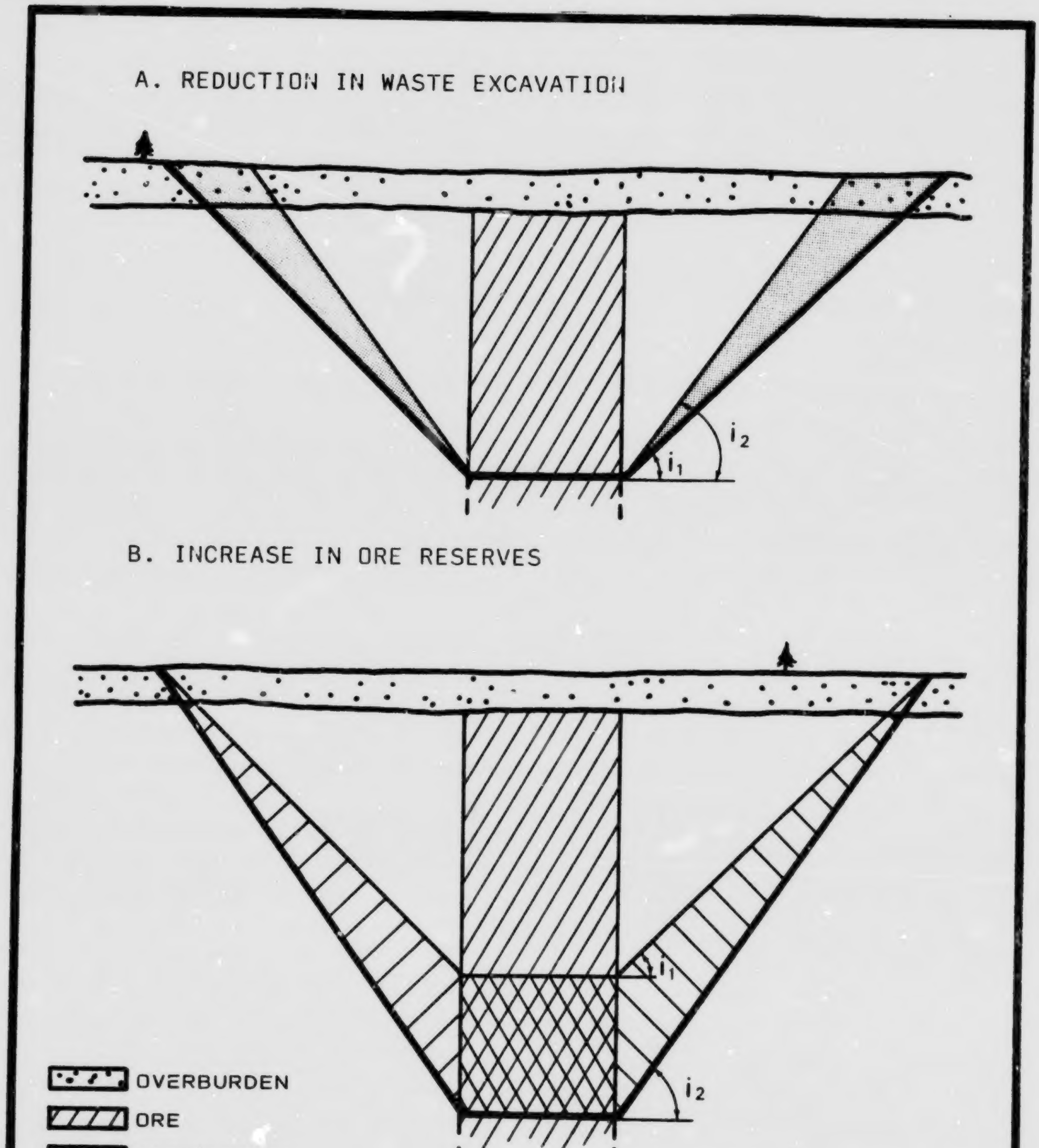
A. REDUCTION IN WASTE EXCAVATION
i_2
i_1
B. INCREASE IN ORE RESERVES
i_1
i_2
OVERBURDEN
ORE
WASTE ROCK
REDUCTION IN WASTE
INCREASE IN WASTE
INCREASE IN ORE RESERVES
$i_2 - i_1$: INCREASE IN OVERALL PIT SLOPE ANGLE

Figure 7. Possible Economic Effects of Steepening the Overall Pit Slope Angle

If the increase in pit slope angle is used to reduce the amount of waste excavation, this improvement can take one of two possible forms. Most likely, the existing ore capacity would be maintained, resulting in a decrease in annual operating costs. Alternatively, the cost reduction could provide economic justification for an increase in ore capacity, increasing annual cash flows and reducing the remaining mine life.

If the steepening in pit slope angle is applied to increase recoverable ore reserves, the existing ore capacity could again be maintained. In this case, the increase in ore reserves would have the benefit of lengthening the remaining mine life. Alternatively, the increased ore reserves could provide the basis for an expansion of mine capacity, increasing annual cash flows, and more marginally extending mine life.

There will generally be large differences in the magnitude of benefits, the risks, and the capital requirements among these alternatives. In practice, mine management will likely endeavour to achieve some balance among these alternatives for realizing benefits from steepening the overall pit slope angle.

An Overview of Literature on Pit Slope Technology

This section provides an overall impression of the advances in pit slope technology which have been made to date. It is based on an appraisal of the professional literature on the subject. The purpose is to provide a framework for evaluating the role of the CANMET pit slope project.

Prior to 1965, very few significant contributions were published on the subject of rock mechanics as applied to open pit slope stability. This reflected an historical focus on underground mining, the consequent underground orientation of mining engineering education, and lack of appreciation of the benefits associated with improved open pit technology.

This situation began to change in the late 1960s, mainly because of the demand for technological change created by substantial growth in the scale, annual tonnage, planned depth, and economic importance of open pit mining. Nowhere was this change greater than in Canada, as outlined earlier in this chapter.

The seventies was a decade of rapid change in awareness of the problems and opportunities related to the stability of open pit slopes. From 1970 onwards, as a result of seminars, conferences, and technical publications, mine operators began to ask questions regarding design, control, and improved efficiencies of their pit walls.

Indicative of this increasing awareness is a numeration of published papers on the subject. Figure 8 shows the number of published Canadian contributions in the field of rock mechanics as applied to open pit slope stability during the period 1960-81. These results are summarized in table 3 for five-year time intervals.[16]

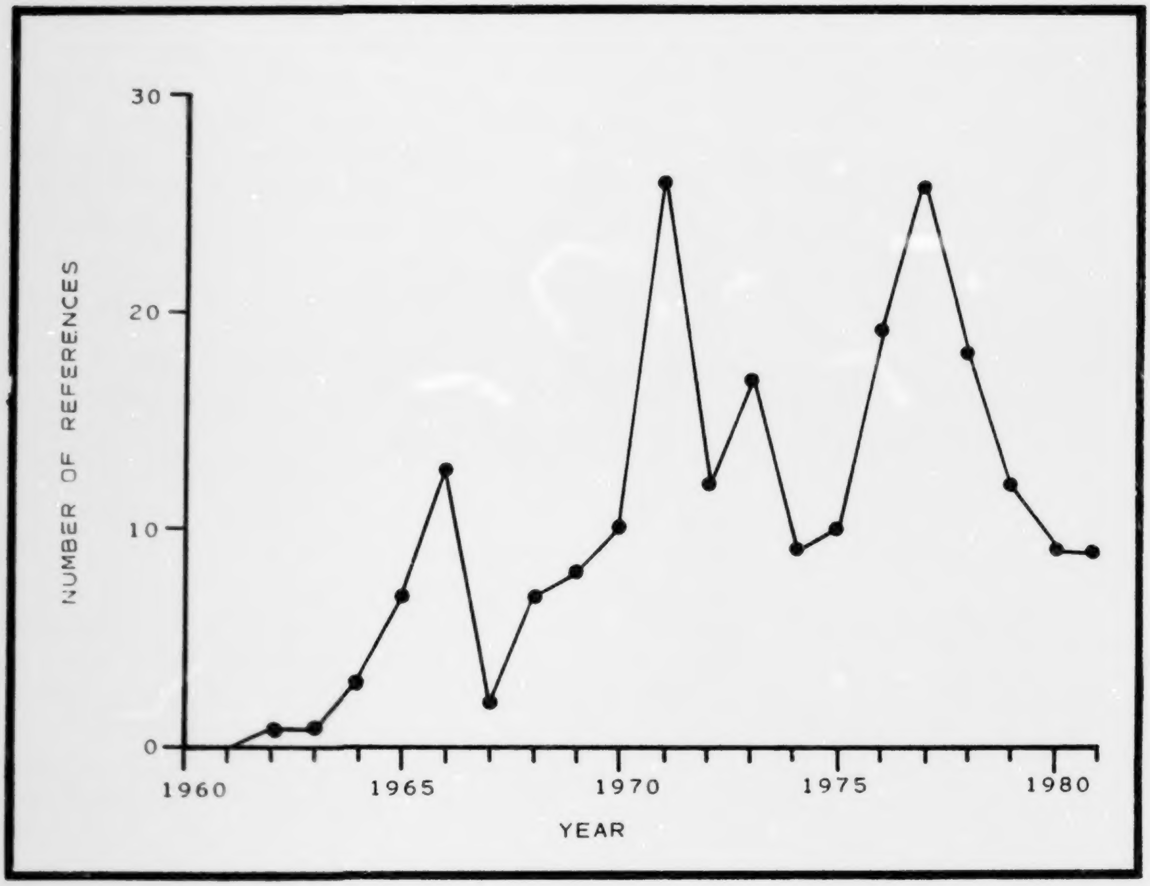

Figure 8. Published Canadian References on Open Pit Slope Stability

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[16] These figures have been derived from the bibliography of Canadian contributions in the field of rock mechanics compiled by The Canadian Advisory Committee on Rock Mechanics. See 'A Bibliography of Canadian Contibutions in the Field of Rock Mechanics', CIM Bulletin, May 1964, and the eighteen annual supplements, also published in the CIM Bulletin, from March 1965 to August 1982. The papers included are by Canadian authors or they have been published in Canadian journals. We have only included published papers related to open pit mining.

Table 3

SUMMARY OF PUBLISHED CANADIAN
REFERENCES ON OPEN PIT SLOPE STABILITY

Time Period	Number of References
1955-59	0
1960-64	5
1965-69	37
1970-74	74
1975-80	85

Although there were a number of important pioneering papers on the subject, three milestones are evident in this historical process of creating awareness and advancing open pit slope technology:

i the international conferences on stability in open pit mining which were convened in Vancouver under the leadership of C.O. Brawner in 1970 and 1971;[17]

ii publication of Rock Slope Engineering by E. Hoek and J.W. Bray in 1974;[18]

iii the CANMET pit slope project carried out in 1972-77 and published as the Pit Slope Manual in 1976-77.[19]

The 1970 conference in Vancouver emphasized the need to link theoretical design techniques to the analysis of actual pit slope failures. Attention was given in the proceedings to assimilation of information and assessment of technology as applied to actual mining experience and particular case studies. The second conference in 1971 resulted from interest generated by the first. Once again, the main focus was practical case studies.

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17. The proceedings of these two conferences were published as follows. Stability in Open Pit Mining, C.O. Brawner and V. Milligan (editors), American Institute of Mining Engineers, New York, 1971. Geotechical Practice for Stability in Open Pit Mining, C.O. Brawner and V. Milligan (editors), American Institute of Mining Engineers, New York, 1972.
18. Rock Slope Engineering, E. Hoek and J.W Bray, Institution of Mining and Metallurgy, London, 1974.
19. Pit Slope Manual, ten chapters with supplements, 27 volumes, CANMET, Energy, Mines and Resources Canada, Ottawa, 1976 and 1977.

These two conferences, and the resulting proceedings volumes, clearly demonstrated the opportunities which existed for advances in pit slope technology and indicated the economic benefits that would be associated with such advances.

Rock Slope Engineering by E. Hoek and J.W Bray describes tools and techniques to assist civil and mining engineers in collecting slope stability data quickly and efficiently, and processing it systematically. Application of these methods is illustrated by a number of worked examples. Emphasis is placed on design charts and graphical methods to enable non-specialist engineers to obtain approximate solutions and then, if necessary, to interface with geotechnical specialists. A practical handbook, in a single volume, using the proven 'factor of safety' approach to design, this text shows what can be achieved by private enterprise. The demand for this handbook has resulted in publication of a revised and extended second edition in 1977, and a third edition in 1980.

The Pit Slope Manual had generally the same intent as the Hoek and Bray handbook. The CANMET project and manual are described in chapter 4. The manual focuses on open pit mining and on Canadian conditions. It was published in 27 volumes, using an innovative probabilistic 'reliability analysis' philosophy, and reflecting an extensive contracting-out approach to mineral research and development. It was prepared under government coordination, and draws on expertise from mining companies, geotechnical consultants, and universities.

Rock Slope Engineering and the Pit Slope Manual are far and away the two most widely used references on pit slope stability in the Canadian mining industry. Their perceived strengths and weaknesses are examined in chapter 7. Both texts have made important contributions to the advancement of pit slope technology.

In 1981, after a passage of ten years, a third international conference on stability in open pit mining was held in Vancouver.[20] The purpose of the conference was to document the many advances in technology made during the period, and thus to upgrade the state of knowledge concerning the stability of open pit mines. An examination of the proceedings volume in terms of contributing authors, case studies described, acknowledgements made and references cited indicates that the CANMET pit slope project made a significant contribution to advancements in pit slope technology during this decade of rapid change.

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[20] Stability in Surface Mining, C.O. Brawner (editor), American Institute of Mining Engineers, New York, 1982, 872 p.

4. THE CANMET PIT SLOPE PROJECT

Original Justification

Studies carried out in the early seventies by the Mining Research Centre[21] assessed the potential benefits and costs of research on rock slopes.[22] The justification of the CANMET pit slope project was based on these analyses. A brief summary of this justification is presented here.

At the outset, this work recognized that production from open pit mines in Canada was growing at a rate of more than 10 percent per year, that the volume of ore obtained from open pits was greater than for underground mines, and that the proportion was growing. Furthermore, the studies showed that open pit mining costs are strongly influenced by the large amounts of waste rock excavated and, hence, by the slope angle which is used for the pit walls.

The economic theory of the firm[23] was examined, and then modified and applied to evaluate the economics of open pit mines. This theoretical model was used to assess the reduction in costs which would be associated with increasing pit slope angles. Also, the possible effects of such an improvement on production rate and ore reserves were examined. The model developed, based on marginal cost analysis, was used to estimate the benefits which would accrue from successful pit slope research.

All open pit mines contributing to ore production in Canada at that time were reviewed. Wide variations in slope angles were observed to result from variations in rock types and in personal judgments. It was found that in the majority of cases slides rarely occurred, which, together with the fact that there was no technically rigorous method of designing pit slopes comparable to that used for civil engineering structures, suggested that a larger than necessary safety margin existed. Optimum pit slopes could be designed with assurance, it was asserted, only if and when research and development work provided the required scientific procedures for analyzing the behaviour of rock slopes and established practical engineering techniques for their application.

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[21] Part of the federal government's Mines Branch, reorganized and renamed CANMET in 1974.

[22] See Benefits and Costs of Research on Rock Slopes, D.F. Coates and A. Dubnie, MR71/50-ID, May 1971, and Elements of Planning Affecting Rock Slope Design for Open Pit Mines, D.F. Coates, MR-71/77-LD, July 1971, internal reports, Mining Research Centre, Department of Energy, Mines and Resources.

[23] The classical theory of the firm provides a simplified representation of the optimization of an industrial plant, considering revenue, cost, and profit as functions of the rate of production.

Specifically, means of quantifying structural geological properties and rock material properties were needed.[24]

Thus as a result of this examination of open pit mining conditions in Canada, potential was perceived for research applied to the design of optimum pit slope angles. It was judged that an appropriate research and development program would lead to a minimum average increase in slope angle of 2.5 degrees and an expected average increase of 5 degrees for approximately 75 percent of open pit production.

It was found that individual mining companies were reluctant to undertake a comprehensive research program on pit slope stability due to the time and cost involved in relation to the relatively short lives of their individual mines and restricted impact on their specific operations. Hence, this applied research, which was considered important to the country as well as to the mining industry, would best be undertaken, it was suggested, by government or by some other enterprise serving the overall industry.

An estimate was then made of the cost of the necessary research and development work required to be able to design rock slopes explicitly, and thus to obtain the projected benefits. Order-of-magnitude cost estimates were based on a five-year research and development program for the establishement of adequate measurement procedures and practical field techniques, followed by a six-year period for integrating the research findings into the actual mining operations. The total estimated project cost was $3.6 million.

With respect to the evaluation of benefits, the main assessment was based on the effects on direct mining costs of the minimum average increase in slope angles of 2.5 degrees for 75 percent of the mining industry's open pit production. It was anticipated that this improvement would be realized in the form of a reduction of 14 million tons per year in the volume of waste excavation. The assessment further assumed no future increase in production, a 50-year life for the mining industry, and a 15-percent discount rate. The cost of the monitoring and support systems required to realize the benefits, considered to be an order of magnitude lower than the benefits, were ignored. Under these conditions, benefits were projected to begin in year 7, building up to a steady-state level of $7 million per annum from year 11 onwards. For comparative purposes, the project cost and benefit streams were discounted back to present value equivalents. Thus, the benefit-cost ratio for the minimum effects on direct mining costs is 6.6. A benefit-cost ratio of 13.2 is associated with the expected 5 degree steepening in slope angle.[25]

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[24] As pointed out in the literature overview in chaper 3, the subject of rock mechanics applied to pit slopes as a specialized engineering discipline was in its infancy in the early seventies. Research was developing rapidly on a theoretical basis at least, with practical aspects, for example material properties determination, just getting started.

Finally, a broader range of potential benefits associated with this proposed mining research and development project are discussed. These were considered to include reduction of indirect mining costs, increases in recoverable ore reserves, expanded rates of production, and safer working conditions. Attention was also given to possible benefits to regional activity, particularly northern development, and to benefits for the national economy in terms of higher tax revenues, increased employment, and enhanced foreign exchange earnings.

The argument advanced in this original justification of the CANMET pit slope project concludes with the summary statement that 'there is a good probability that the benefit-cost ratio for this work exceeds 100.'[26]

Project Implementation

The studies carried out at the Mining Research Centre culminated in a submission to Treasury Board for funding in 1971. The proposal was for a project lasting ten years (1972-73 to 1981-82), with the objective of producing a comprehensive engineering manual for the design of open pit mine slopes by 1977. The five years beyond 1977, following publication of the manual, were intended to allow for a period of technology transfer, utilizing conferences, industry seminars,and company workshops to encourage best use of the manual by the mining industry.

Treasury Board, no doubt influenced by the attractive benefit-cost ratio indicated, approved the spending of $3.95 million for the project as part of Energy, Mines and Resources' objectives of 'ensuring the effective use of mineral and energy resources for the present and future benefit of the nation' and 'developing improved mining technology for exploiting Canadian resources.'

The CANMET submission to Treasury Board proposed to contract out 75 percent of the research and development work to the private sector and universities.[27] This feature resulted from recognition of the nature of the technology involved and the intellectual resources which would have

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25. The estimates and evaluation procedure adopted can be found in Coates and Dubnie, pp. 12-14, and figure 7 on p. 22. It has not been possible to reproduce the benefit-cost ratio of 40 cited in the report. This perhaps includes allowance for reduction in indirect mining costs as well as other anticipated benefits.
26. Coates and Dubnie, p. ii
27. See Pit Slope Project - a Case Study of Contracting-Out, G. Bartlett and D.F. Coates, CANMET Report 78-17, September 1978.

to be tapped to produce the required result. Slope stability technology requires the integration of specialist knowledge across several disciplines. This characteristic of the project required the use of a wide representation of expertise available in Canada and elsewhere.

The intention to contract out 75 percent of the research and development work coincided with the 'make-or-buy' policy of the federal government which was being formulated at that time. This policy, proclaimed in 1972, places the onus on government departments to contract out all research, except where it can be demonstrated according to a prescribed set of conditions that it should be undertaken in-house.

Treasury Board indicated approval in principle of the CANMET pit slope project in 1971 and final approval followed in April 1972. Two conditions were attached to the project by Treasury Board:

i because of the potential benefits accruing to the mining industry, outside organizations should contribute about 50 percent of the overall project cost, i.e. Treasury Board's $3.95 million allocation should be approximately matched by industry;

ii an annual evaluation of the progress of the previous year be undertaken using performance measures prescribed by the Selection Committee.

Imposition of the first condition effectively meant that the contracting-out aspect of the project was not entirely independent of Treasury Board. Since companies and universities could not plausibly provide cash for work to be performed internally at CANMET, the cost-sharing proviso would have meant some form of direct external participation in any case. In fact, the intention was to value the contributions of mining companies, consulting engineers and universities at commercial rates, considering them as costs against the project.

During the process of project definition at CANMET, the aspects which were deemed essential to control and performance, such as scientific supervision, integration and synthesis of material, and final preparation of the manual, were retained by CANMET, together with about 30 percent of the primary research. The remaining activities, the bulk of the primary research together with virtually all the development work, were contracted to outside organizations. Although the target of contracting out 75 percent of the research and development work was decided upon early in the planning process in a rather arbitrary manner, the actual logistics of the project in fact determined an eventual division of tasks not markedly different from the initial plan.

Scientific management of the pit slope project was exercised through two lines of control. An interdepartmental Selection Committee, made up of officers of CANMET, Geological Survey of Canada, Department of Supply and Services, and Treasury Board, ruled on the awarding of research and development contracts. A number of designated scientific authorities then supervised the month-to-month progress of the project. The Department of Supply and Services handled the contractual arrangements. CANMET's Research Program Office provided the immediate administration of funds.

Research and Development Phase

The purpose of the research and development phase was to prepare an engineering manual for the geotechnical design of open pit slopes, and for the design of waste embankments.

Following approval in principle of the project in 1971, a briefing session with representatives of industry and government departments was arranged, and invitations to tender for the work were sent to interested organizations. The Selection Committee chose the successful contractors, and contract negotiations were completed by the end of 1971. Official notification of Treasury Board approval for implementation was given, contracts were signed, and work started on 1 April 1972.

Nine contracts, involving 19 mining operations, five universities and six consulting engineering firms were let in the first year of the project (1972-73). Work in the first year was concerned with defining the objectives of the project, collecting and collating source material, and initiating research and development. At mid-year, the work status was reviewed and objectives for the second year drawn up. Requests for proposals were again issued, and review and selection of successful proposals by the interdepartmental Selection Committee were completed by early 1973. Contracts were signed in March 1973.

The scope of operations was expanded greatly in the second year, 1973-74. Altogether, 20 mining operations, nine engineering firms, and nine universities participated through 14 contracts. The year saw an intense period of applied research in the field, analyses of data, and initial drafts of the engineering manual for pit slope design. Requests for proposals were again issued in October 1973, and the process of reviewing, selecting and awarding of contracts resulted in still further expansion of work for the third year.

Twenty contracts were let for the third year of the project, 1974-75, involving 37 mining operations, ten engineering firms and nine universities. Specific work in the third year included refinement and expansion of the field work, initiation of actual trials of the tentative recommendations, and redrafting of the manual chapters.

The main objective for the fourth year (1975-76) was to complete the research and development already underway. In addition, substantial efforts were devoted to evaluation of the draft manual, including actual field trials. Twenty-three contracts were let involving some 20 mining operations, 12 consulting engineering companies, and seven universities. At the end of the fourth year of the project, substantial drafts of the various sections of the manual were completed and distributed to industry for appraisal and review.

The fifth year (1976-77) was devoted to additional research and development work in the light of outside reviews, and to redrafting the manual. The final 12 contracts were undertaken, completing the research and development phase. Emphasis shifted to the final stages of manual publication and to the technology transfer phase.

Seventy-eight contracts were awarded to 42 outside organizations over the course of the project. Of the 42 contractors, seven were universities, two were non-profit research councils, nine were mining companies, and 24 were consultants. Three of the contracts involved consulting firms based outside of Canada.

The contribution of contractors were made in various ways. Mining companies generally donated a substantial part of the cost of facilities, labour and equipment. Consulting engineering firms generally performed research and development at cost, i.e. payroll burden plus direct expenses. Their contribution was, thus, the reduced overhead and uncharged profit. Universities generally performed research and development at a negotiated rate substantially below the scale of changes normally accepted by the Department of Supply and Services. Both consultants and universities enlisted the cooperation without charge of other groups, particularly mining companies, which provided facilities and sometimes equipment at no charge, or released information compiled or purchased earlier by themselves. Where a realistic value of this cooperation could be assessed, this was counted as a contribution.

The Pit Slope Manual

By mid-1976, work on the CANMET pit slope manual was far enough advanced for a summary chapter (chapter 1) to be published, and for the manual to be formally announced. At the original target date of March 1977, five chapters of the manual had been printed and distributed. The complete Pit Slope Manual, containing ten chapters with supplements, totalling 27 separate volumes, was published in July 1977.

The Pit Slope Manual is intended to be a practical working tool for mine staff to use on their properties. There will always be problems requiring experience and expertise beyond the guidance supplied by the manual. However, the purpose of the manual is to place the capability to recognize the need for, and be able to implement, rational slope design into the hands of open pit mine operators.

Each chapter was issued as a 'stand alone' package, bound separately, for convenience, and divided into two sections. The main section describes the problem dealt with in the chapter and provides recommended solutions. It is written for those with overall responsibility for mine design and planning, such as the chief mining engineer and mine manager. Detailed descriptions of the techniques employed are given in appendices and supplements to the chapter, which are intended for the more specialized geologist or engineer.

The pit slope manual defines three broad aspects of geotechnical pit slope design. One is the investigations needed to measure the field properties required as input data for slope analysis. The second is design, which covers slope stability calculations and overall financial risk and cost-benefit analysis of the mine layout. The third is control, which deals with measures required to monitor slope performance to ensure that the designed stability is maintained, and measures that can be used to improve stability. Seven chapters, summarized below, deal with these three aspects.

1. Structural Geology
   In most rock slopes, discontinuities such as joints, faults and bedding planes govern stability. This chapter, and supplements to it, describe methods of systematically measuring these discontinuities, recording and analyzing the vast information in a meaningful way so that appropriate data for design can be obtained.

2. Mechanical Properties
   Properties such as shear strength of discontinuities and the strength of intact rock are of prime importance. This chapter and supplements to it describe the properties of slope material required for analysis of stability and discuss in detail the field and laboratory techniques for measuring these properties.

3. Groundwater
   Groundwater is often of great significance in stability. This chapter and the appendices to it describe the role of groundwater in reducing the shear strength of slopes, ways of measuring groundwater pressure and flow, and analytical methods of extrapolating these measurements to determine its influence on an entire slope. Slope stabilization by drainage is also described.

4. Design

   This chapter describes the actual process of analysis and design of slopes from a geotechnical point of view, using data defined in the investigations of structural geology, mechanical properties, and groundwater conditions. Both detailed and approximate methods of slope design are included. The chapter emphasizes the case for the reliability approach to slope design, and the value of economic risk analysis.

5. Mechanical Support

   Mechanical support, such as deep rock anchors, can be a viable means of achieving increased slope angles. This chapter describes the methods of support, their relevance to stability, and techniques for their design and installation.

6. Perimeter Blasting

   Blasting inevitably affects rock in a slope face, usually reducing stability. Control blasting can have great benefits in maintaining the integrity of a rock face, permitting steeper benches and therefore steeper overall slopes. The chapter describes the various methods of control blasting, the techniques of calculation and design of those blasting methods, as well as the techniques of monitoring blasting effects.

7. Monitoring

   Steepening pit slopes cannot be considered unless the slope behaviour is continually monitored. This chapter and appendices to it describe instruments and procedures that should reveal deviations from expected behaviour in time for action to ensure safety of men and equipment, and avoid disruptions of production. Descriptions of automated remotely-read equipment are also included.

The seven chapters outlined above form the essential slope design section of the manual. Three other chapters are included. One describes the design of mine waste embankments, with stability being the main consideration. Another deals with environmental planning in open pit mining, including revegetation. Finally, a summary chapter is provided, allowing the reader an overview of the entire manual before becoming involved in details of the individual chapters.

Technology Transfer Phase

Publication of the Pit Slope Manual was formally announced in October 1976, at the 11th Canadian Rock Mechanics Symposium in Vancouver. The pit slope project formed the central theme of the symposium, with presentation and discussion by contractors and in-house professionals involved in the project.

In early 1977, a task force on planning workshops for the pit slope manual was formed, including 17 mining company representatives. A letter was sent to each task force member, asking them for advice concerning for whom the workshops should be organized, and the most appropriate format, style, location, and duration. A meeting of the task force was convened at Ottawa in April 1977 to discuss these matters further. It was decided to hold two three-day workshops. The purpose of these workshops was to brief open pit mine designers and planners on the contents of the manual, and to create an awareness of potential benefits associated with its application. At the same time, feedback was sought to ensure that the manual followed the format best suited to practitioners.

The first workshop was held at Calgary in September 1977. There were 38 participants, 26 from Canadian mining companies representing 15 open pit mining operations. The second workshop was convened at Montreal in October 1977. There were 33 participants, 25 from Canadian mining companies representing 13 open pit mining operations. After these workshops, CANMET audio-visual packages highlighting the manual and its use were revised and offered on loan. These have been sent on request to 15 mining companies. A further workshop on the pit slope manual was held at Thompson in May 1978. Twenty-nine participants from three mining companies attended. Also in 1978, similar workshops were convened at Faro, Cassiar, and Endako.

In 1979, the sub-committee on rock slopes of the Canadian National Committee on Rock Mechanics undertook an industry-wide survey of users of the pit slope manual. A questionnaire on the use of the manual was prepared and sent to 125 prospective users. Forty responses were received and their results compiled. These results are included in chapter 7.

Cost of Pit Slope Project

The cost of the CANMET pit slope project, in current dollar terms, totalled about $4.81 million. Government funding was the source of 63 percent of this total. Industry and university contributions provided the remaining 37 percent. With respect to government funding, 51 percent was applied to research and development contract payments, 26 percent was used for in-house research, and the remaining 23 percent was expended on publishing the manual, technology transfer, and administrative services. The contracted-out portion of the research and development work was funded 47 percent by government payments and 53 percent by industry and university contributions. Of the total funds, about 69 percent was contracted out and 31 percent was used in-house.

Table 4 shows the cost of the pit slope project, in current dollars, estimated on a calendar-year basis. The gross national expenditure implicit price index is applied to convert these values to constant 1980 dollars, the standard used in our study. On this basis, the cost of the pit slope project is $8.21 million. Finally, an 8-percent weighted average cost of capital, in constant money terms, is assumed for this investment in mining research and development, and applied to bring the time distribution of project costs to 1982, the date we have selected for comparison of study costs and benefits.[28] Thus, the cost of the pit slope project totals $15.29 million, valued in constant 1980 dollars at 1982.

Table 4

COST OF CANMET PIT SLOPE PROJECT
($ thousand)

Year	Current Money Terms[a]	Constant 1980 Dollars[b]	Constant 1980 Dollars at 1982[c]
1972	562	1 198	2 587
1973	1 129	2 204	4 406
1974	1 147	1 941	3 593
1975	1 166	1 783	3 056
1976	501	699	1 109
1977	174	227	334
1978	88	108	147
1979	41	46	58
Total	4 803	8 206	15 290

[a] Assumes uniform distribution of financial-year cost estimates.

[b] Based on gross national expenditure implicit price index.

[c] Applies 8-percent cost of capital to bring constant dollar costs to equivalent values at 1982.

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28. The 8-percent discount rate is our best estimate of the cost of capital which typifies investment in the mining sector.

CANMET Project Philosophy[29]

The stability of open pit walls depends on the relationship between the force resisting impending motion along a potential failure surface (or, the strength of the rock mass), and the disturbing force which acts on that surface (or, the stress). As long as the strength of the rock mass is greater than the stress, open pit walls will remain stable. In instances where stress exceeds strength, failure will occur.

The geological environment associated with open pit mines is inherently variable. This variability occurs both within and among mineral deposits, as well as in the surrounding waste rock. Geological variability has important implications for a wide range of mining and mineral processing activities, including the design and control of pit slopes.

One consequence of this geological variability is that the strength and stress characteristics of open pit walls, no matter how much testwork is carried out, are inherently uncertain. This is illustrated by the bell-shaped distributions of strength and stress characteristics in figure 9. Thus, the stability and failure possibilities for pit slope walls are probabilistic. The characteristics of the strength and stress distributions vary among operations, and among pit walls within a particular mine. The probabilistic nature of rock strength and the stress on pit walls may or may not be explicitly recognized in design practice.

Stress is a function of the pit slope angle. Slopes can be made more stable by making them flatter. However, this usually means excavating more waste rock at considerable additional cost. If steeper slopes are considered, waste costs will be reduced but the chances of instability increase. The costs of instability may include injury to personnel, clean-up costs, delayed production, and loss of ore reserves.

Traditionally, in slope design practice, instability is regarded as unacceptable. The design is considered to have failed if a slide occurs.[30]

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[29] The clearest statement of this philosophy is given in 'Pit Slope Manual Incorporates Results of Many Years of Effort in Development of Reliability Analysis Procedures for Mine Walls', R. Sage, The Northern Miner, November 25, 1976, p. D7.

[30] The diametrically opposed concept that no failure within an open pit indicates an overly conservative geotechnical design and the unnecessary expenditure of funds, now widely accepted, appears to date back to at least 1970. See 'The Role of Slope Stability in the Economics, Design and Operation of Open Pit Mines', R.M. Stewart and B.A. Kennedy, pp. 5-21 in Stability in Open Pit Mining, C.O. Brawner and V. Milligan (editors), American Institute of Mining Engineers, New York, 1971, 242 p.

In the conventional design of open pit slopes, testwork results are analyzed and reduced to single-point estimates of the strength and stress characteristics of a planned open pit. The stress estimate, of course, varies as a function of the assumed pit slope angle. The single-point estimates may be the expected or mean values of strength and stress, or these expectations may be adjusted to values which are considered more representative. In any case, a safety factor for the slope is determined as the ratio of strength to stress values. For example, in figure 9, the safety factor using the expected value estimates of strength and stress would be $EV_A:EV_B$ or 2.0.

A pit slope angle is selected which is considered to give an 'acceptably' high safety factor. Conventional practice is to regard a slope as

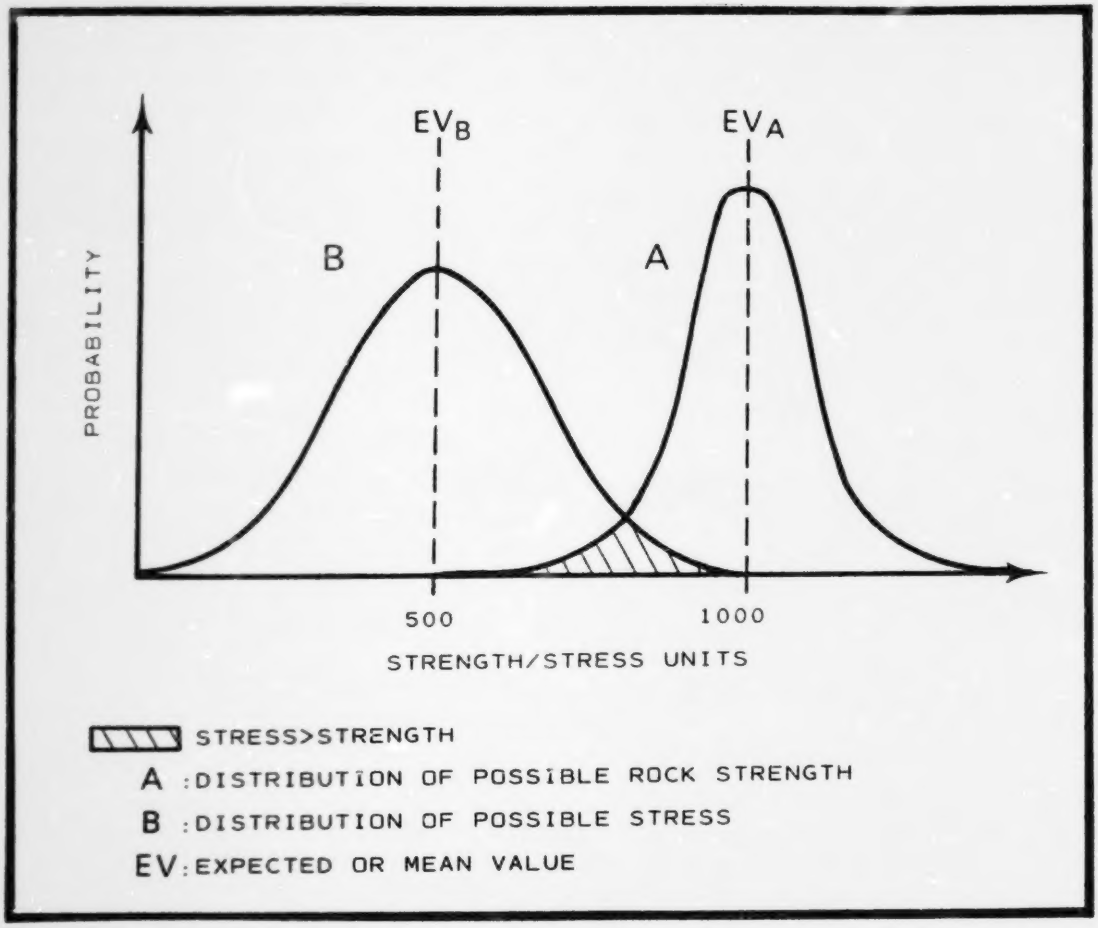

Figure 9. Strength and Stress Characteristics of Pit Slopes

'stable' if the safety factor is sufficiently greater than one. This factor-of-safety hurdle is determined on the basis of past experience and knowledge of the situation at hand.

In practice, however, there is no assurance that any slope is stable because of the inherent uncertainties associated with the strength and stress variables. As a result of these uncertainties, a high rock strength may occur with a low stress, resulting in a particularly stable slope. On the other hand, a low strength may coincide with a high disturbing force or stress, and instability - corresponding to the hatched area in figure 9 - may result.

The design philosophy which underlies the CANMET pit slope project differs from the conventional approach to design outlined above in two important and interrelated respects.

i Rather than regarding instability as unacceptable, the CANMET design philosophy acknowledges the possibility of pit slope failure. Provided proper precautions are taken to ensure the safety of personnel, the pit slope design and, particularly, the choice of pit slope angle, are considered to be matters of economics. Thus, the objective of the design process might, for example, include selection of pit slope angles which minimize the combined cost of waste excavation and instability.

ii A probabilistic 'reliability analysis' procedure is applied for the analysis of testwork results, to provide estimates of the uncertain distributions of possible strength and stress values as illustrated in figure 9. This, it is suggested, is an advantage simply because it includes more useful information in the design process than is the case conventionally, when design is based on single-point strength and stress estimates. The intention of this analytical procedure is to provide a more realistic picture of what actually happens when a slope is mined. Thus, the probability of pit slope failure can be directly assessed, and controlled by appropriate selection of pit slope angles. Also, it is asserted that results provide a better basis to assess the precautions required to insure safe working conditions.

5. ASSESSMENT OF DIRECT BENEFITS ATTRIBUTABLE TO CANMET PIT SLOPE PROJECT

This chapter outlines the estimation and evaluation procedure applied to assess, retrospectively, the direct benefits attributable to the CANMET pit slope project at established open pit operations in the Canadian mining industry.

Mine visits and interviews have yielded 20 quantifiable cases of actual technological advances at existing mining operations which have realized benefits attributable in part to the CANMET pit slope project. In view of the imprecisions which are an integral part of the interview process, we have endeavoured to treat the interview results in a conservative manner. The attributable benefits which have arisen from these cases are evaluated and analyzed. They are then scaled up to provide an estimate of direct benefits for the Canadian mining industry, and a quantifiable benefit-cost ratio for the CANMET pit slope project. Finally, our assessment of what has actually happened is compared with the prospective evaluation made in the original justification of the CANMET project.

Case Study Evaluation

The assessment of benefits considered here is restricted to the 20 cases outlined in appendix IV. These 20 case studies represent 17 separate mining operations and 13 centres of mining activity. Eighteen of the case studies concern open pit mines, one relates to an underground mining operation, and one considers an application in the administration of government mining regulations.

Estimation and Evaluation Procedure

All money values used for evaluation purposes are in constant 1980 dollars. The gross national expenditure implicit price index is used to convert actual historical information and estimates to 1980 dollar equivalents.

The estimation and evaluation procedure followed is depicted in figure 10. The starting point for each case study is the estimation of a time distribution of cash flows resulting from the technological change. There are three elements to this evaluation.

First, the cost of implementing the change is estimated. This includes the direct investment and time required to assemble the necessary base of technical data, and to carry out associated pit slope stability and mine design studies. Also included are the costs of any additional equipment required. However, expenditures incurred by industry and government under contract as part of the CANMET pit slope project are excluded, being included in chapter 4 as part of the CANMET project cost.

Secondly, the physical effects of each of the case study advances are defined. In most cases, the changes in applied technology result in either a reduction in waste excavation or an increase in recoverable ore reserves. Other effects include direct saving in mechanical support and drilling requirements, improvement in recoverable ore grade, and prevention of temporary mine shutdowns.

Finally, supporting estimates are required to evaluate the economic consequences of these physical changes. These vary among the cases but may include: the cost of waste removal; ore mining and milling costs; ore grades; mill recovery factors; ore, concentrate and metal prices; and drilling, blasting, monitoring, and mechanical support costs.

The estimates of implementation costs and physical effects are in all cases based directly on data obtained from the interviews conducted, as are the supporting economic estimates wherever possible. These are supplemented when necessary with order-of magnitude estimates based on generalized Canadian mining industry experience.[31]

While all of these factors are to some degree uncertain, we have generally considered it sufficient for study purposes to represent them by single-point most-likely estimates. The only exceptions are the mine shutdown time in case 7 and the cost of the tailings impoundment manual in case 10. Since these two variables are of strategic importance to their respective case study results, subjective estimates of 90 percent confidence limits are also made to define ranges of possible values on either side of the most-likely estimates. These uncertainties are subsequently included in the risk analysis conducted.

In the first stage of our evaluation, the three estimation elements are combined to assess the time distribution of cash flows resulting from each case study as shown in figure 10. It should be noted that the benefit estimates are net of on-going costs resulting from the technological change.

The time distributions of cash flows for the individual cases, standardized in constant 1980 dollars, are spread over a very long timeframe which starts in 1972 for the initial implementation cost associated with the first cases started (cases 13 to 17) and ends in the year 2003 for the last cash flow benefit associated with the cases having the longest life (cases

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[31] For an outline of these generalized estimates, see Economic Effects of Smelter Controls on the Canadian Nonferrous Mining Industry, B.W. Mackenzie and M.L. Bilodeau, technical paper no. 2, Centre for Resource Studies, January 1982, chapter 3 and appendix III.

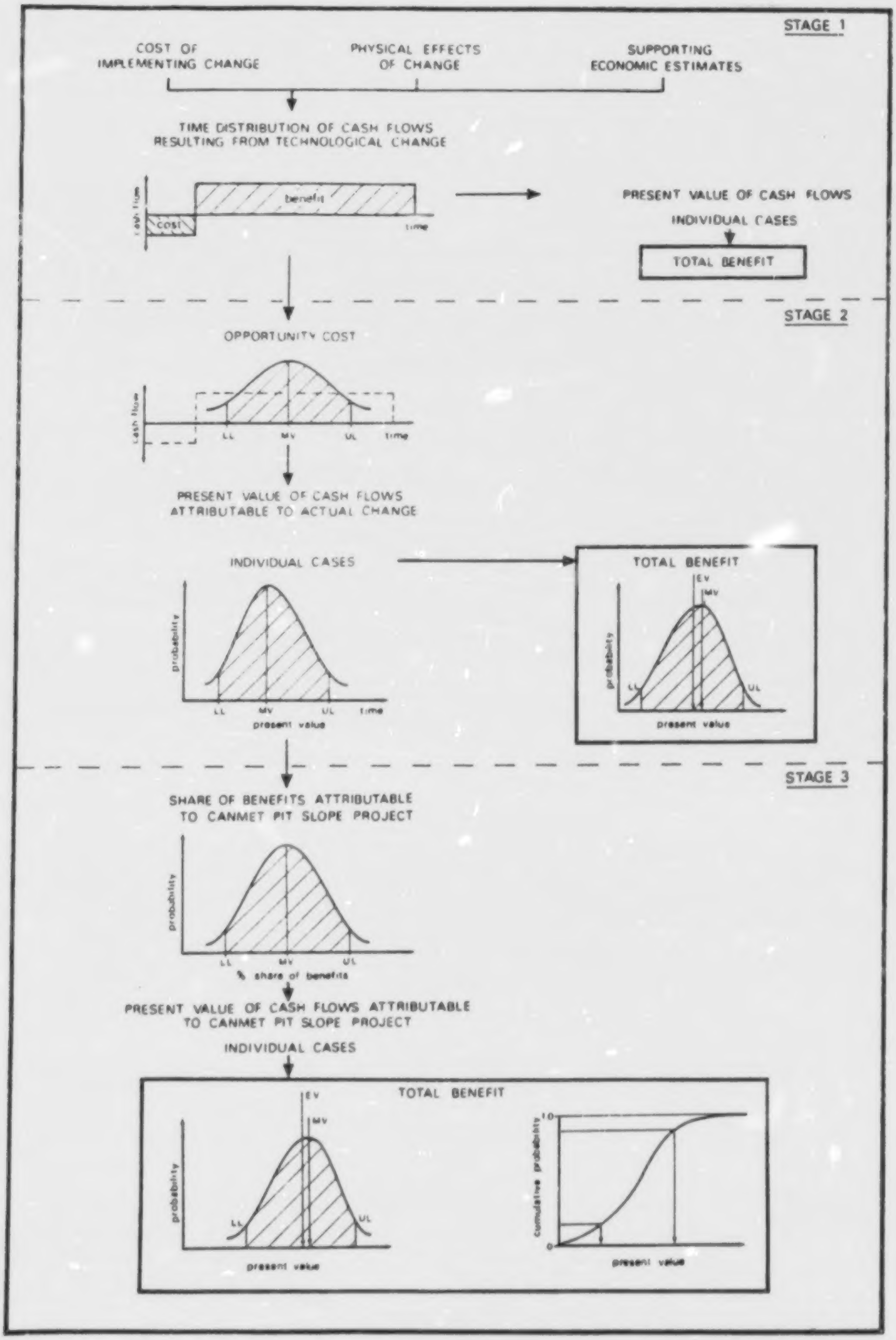
STAGE 1
COST OF IMPLEMENTING CHANGE
PHYSICAL EFFECTS OF CHANGE
SUPPORTING ECONOMIC ESTIMATES
TIME DISTRIBUTION OF CASH FLOWS RESULTING FROM TECHNOLOGICAL CHANGE
cash flow
benefit
cost
time
PRESENT VALUE OF CASH FLOWS
INDIVIDUAL CASES
TOTAL BENEFIT
STAGE 2
OPPORTUNITY COST
cash flow
LL
MV
UL
time
PRESENT VALUE OF CASH FLOWS ATTRIBUTABLE TO ACTUAL CHANGE
INDIVIDUAL CASES
probability
LL
MV
UL
time
present value
TOTAL BENEFIT
EV
MV
probability
LL
UL
present value
STAGE 3
SHARE OF BENEFITS ATTRIBUTABLE TO CANMET PIT SLOPE PROJECT
probability
LL
MV
UL
% share of benefits
PRESENT VALUE OF CASH FLOWS ATTRIBUTABLE TO CANMET PIT SLOPE PROJECT
INDIVIDUAL CASES
TOTAL BENEFIT
EV
MV
probability
LL
UL
present value
1.0
cumulative probability
0
present value

Figure 10. Procedure for Assessment of Case Study Benefits

2 and 3). While the benefits in most cases extend into the future, they are always based on actual changes already in place and already embodied in established operating practices. Thus, the evaluation remains retrospective. The main uncertainty concerning the realization of future benefits is continued operation of the mines themselves. In most of the cases, there is little doubt that these mines will continue to operate as planned.

The cash flow estimates have to be brought to a common point in time to make valid economic comparisons within and among the case studies.

The cases represent investment in applied mineral research and development. An 8-percent weighted average cost of capital, in constant money terms, is assumed for these investment funds and applied to bring each annual cash flow estimate to a common point in time for comparative purposes.[32] 1982 has been chosen as the most suitable valuation date for the assessment of present values.

Thus, one outcome of the stage one evaluation is determination of the present value of cash flows associated with each technological change and their aggregation to give a total present value of benefits resulting from the 20 cases.

The second stage of evaluation considers the opportunity cost associated with each of the case study changes. That is, to what extent does the present implementation of change result in foregoing the opportunity of making a similar change and realizing at least a part of the associated benefit in the future? The benefit of possible future change is charged in our assessment as an opportunity cost against the actual change implemented. For this purpose, we speculate on what would have happened if the change had not been implemented when it was.

In six of the 20 cases (cases 4, 7, 9, 10, 11 and 12), we have decided that there is in fact no such opportunity cost. Reasons are given in the case study documentation as to why, in these instances, if the changes hadn't been made when they were, the associated benefits would have been completely lost.

In the other 14 cases, it is considered probable that a similar change in technology would otherwise have been made at some future date, effectively truncating the cash flow distribution associated with the actual change being evaluated. The importance of this opportunity cost in reducing the benefit attributable to the actual change depends on the length of the total cash flow distribution in relation to the estimated time of otherwise affecting the change.

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[32] As mentioned in chapter 4, the 8-percent discount rate is our best estimate of the cost of capital which typifies investment in the mining sector. We think that mining research and development, such as the CANMET project, is economically worthwhile only if the investment made can at least return this threshold rate. The basis for selecting the 8 percent rate is explained in Effects of Taxation on Base Metal Mining in Canada, B.W. Mackenzie, Centre for Resource Studies, 1979, p. 186.

Our estimates of opportunity cost are conditioned by a general awareness arising from the study that advances in pit slope technology, particularly the more important ones, require a rather improbable combination of circumstances - initiative and awareness of engineering staff regarding the potential for improvement; concepts and confidence to implement change arising from the advice of consultants and government experts; communication, justification, and support from mine management. Mineral technology transfer and application is certainly not a fast, continuous, pervasive process. Rather, it occurs once in a while when a set of unusually favourable circumstances combine. Furthermore, as the case studies illustrate, it often takes several years to bring an opportunity for technological advance to the point of implementation.

Within this general framework, estimates of the time at which change would otherwise have occurred are based on our understanding of the circumstances associated with each particular situation. An advance in technology which moves an operation closer to generally accepted engineering practice (for example, case 6) would likely otherwise be made relatively sooner than an advance which implements more innovative technology (for example, case 3).

It is nevertheless extremely difficult to make number estimates of when changes would otherwise have occurred. Consequently, we consider a wide range of possibilities for each of the 14 cases. This is one of the two main areas of uncertainty for our risk analysis of benefits.

Thus, the opportunity cost is imposed as a distribution of possible times at which the technological change might otherwise have been made relative to the date when it was actually implemented. For this purpose, a most-likely estimate is bounded by 90 percent lower- and upper-limit estimates as illustrated in figure 10. Two conservative assumptions are made. First, it is assumed that the changes otherwise made would be in no way related to the CANMET pit slope project. Second, the cost of implementing these future advances is ignored. In this way, the opportunity cost can be evaluated by the uncertain truncation of the cash flow stream which occurs for each of the 14 cases. For the other six cases, the total time distribution of cash flows is attributed to the actual change.

The second stage of evaluation results in the assessment of probability distributions for the present value of cash flows attributable to the actual changes, individually, as input to the third evaluation stage, and in aggregate, as a measure of the total benefit attributable to the actual technological advances.

The third and final stage of evaluation attributes, for each case, a share of the present value of the stage two benefit to the CANMET pit slope project. This is also a very difficult task and, consequently, these estimates are considered as the second main area of uncertainty for our risk analysis of benefits.[33] Thus, for each case study, 90 percent lower- and upper-limit estimates of percentage share bound a most-likely value estimate as illustrated in figure 10.

What percentage share of the present value of cash flows attributable to each case study change is attributable to the CANMET pit slope project? The subjective estimates are intended to reflect the contribution of the CANMET project to realizing the actual changes and benefits. This includes the possible role played by the CANMET project in creating awareness of the potential for improvement; guiding data compilation, slope stability analysis, and design studies; and in contributing to the implementation of the changes. In each case, the role of the CANMET project and our estimate of the percentage share of benefits attributable to the project are outlined in appendix VI.

These estimates are based on asking engineering personnel associated with each case study the following question: 'How important do you think the CANMET pit slope project was in realizing the actual change?' Through discussion with us, this attribution was quantified in terms of possible percentage shares. Adjustments have been made in several cases in order to apply a conservative standard across all the estimates. We assume an identity between percentage share in terms of 'importance' and percentage share of the truncated cash flow stream attributable to the CANMET project.

The range of percentage share estimates vary from a low 5-15 percent (cases 4 and 11) to a high of 40-60 percent (case 6). For case 10, which involves the physical reproduction and use of one chapter of the Pit Slope Manual, 100 percent of the benefit is attributable to the CANMET project. It is important to note that these shares only apply to the truncated benefit stream after allowing for opportunity cost; no benefit is attributable beyond that. Also, in our initial identification of the 20 cases, there was a natural bias towards discovering those with the strongest relationship to the CANMET project since it was that linkage we were looking for. We have, therefore, selected cases which would tend to give the largest attributable shares of benefits.

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[33] The monte carlo simulation technique is applied for risk analysis. All input distributions are symmetrical and, thus, a normal probability distribution is assumed through the three point estimates in each case. The mid-point value for each distribution represents the expected value, the most-likely (or modal) value, and the median value. We refer to it as the 'most-likely' value because, as the outcome distributions are skewed (due to discounting and truncation effects), the mid-point value of the input distribution corresponds to the most-likely value of the simulated outcome. The uncertain variables are generally assumed to be independent within and among the cases. The main exception is for cases 13 to 17 which are part of the same overall research and development program. Here, it is assumed that the opportunity cost and percentage share variables are each completely correlated across the five cases. A sample size of 1000 has been used in simulating results. A split-normal distribution about the most-likely outcome is assumed in estimating confidence limits for the simulated outcome distributions.

The end result of the three-stage estimation and evaluation procedure is an assessment of total benefit (in present value terms) attributable to the CANMET pit slope project. This result, initially simulated as a probability distribution, is most usefully expressed as a cumulative probability function for determination of appropriate confidence limits, and probabilities of realizing particular levels of benefit.

Presentation and Analysis of Results

Based on most-likely values, the aggregate time distributions of cash flow associated with the three stages of evaluation, for all 20 cases, are presented in figure 11.

The first stage of our evaluation yields a most-likely present value of cash flows resulting from the 20 case studies of $232 million, evaluated using an 8-percent cost of capital to bring all values to 1982. The most-likely present value of cash flows attributable to the actual advances, after allowance in stage two for the opportunity cost of future change, is $169 million, or 73 percent of the stage one total. There are three main reasons why this share is so large.

i In six cases, the total time distribution of cash flows is included.

ii In several other cases, cash flows are realized for only a relatively short period from the date of implementation. Thus, there is little scope for possible future change to capture a significant part of these benefits.

iii Time value. The truncated cash flow stream is closer to the present than the part which is foregone, so that, in present value terms, it is relatively important. In terms of undiscounted cash flows, the stage two result represents 65 percent of the stage one total (as compared to 73 percent in present value terms).

The simulated probability distribution for the present value of cash flows attributable to the actual advances is presented in figure 12. The

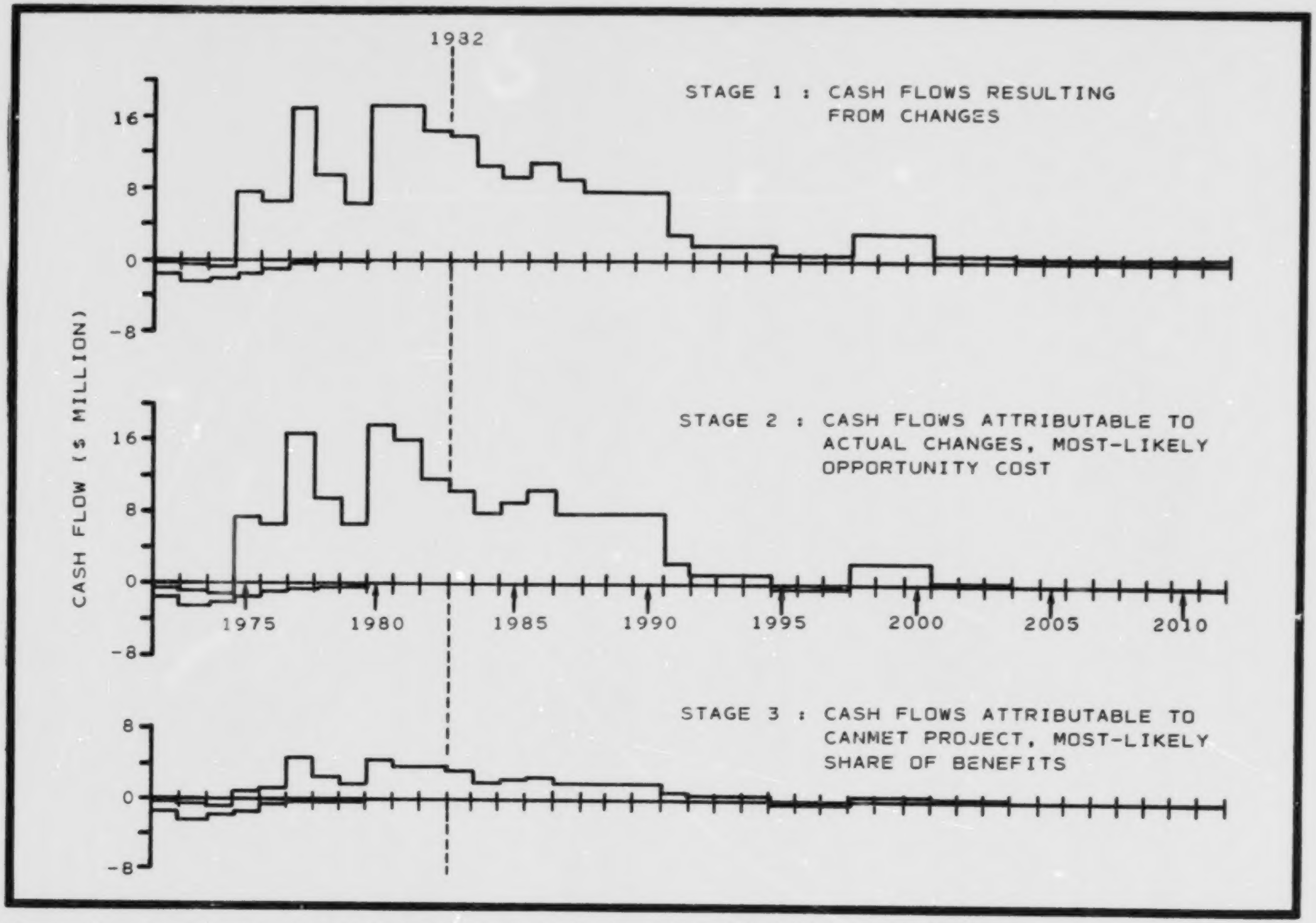

Figure 11. Aggregate Time Distributions of Cash Flow Associated with Case Studies

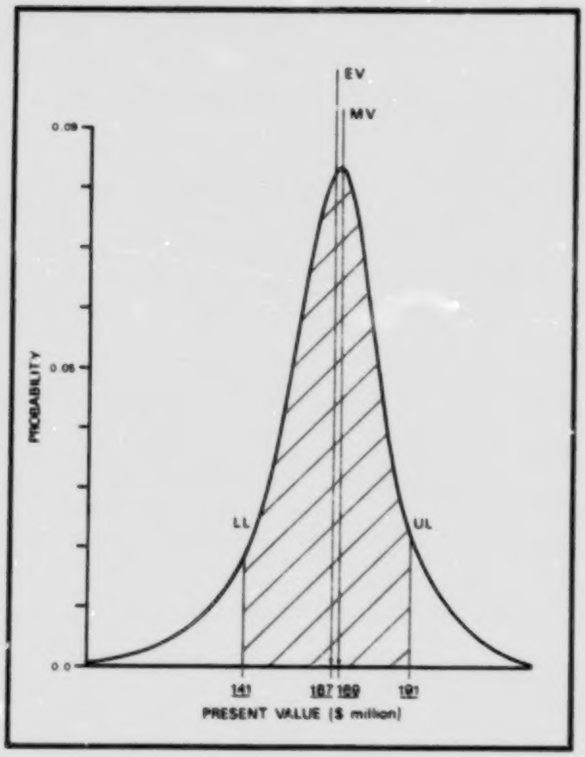

Figure 12.
Present Value of Cash Flows Attributable to 20 Actual Case Study Advances

difference between the expected value (EV) of $167 million and the $169 million most-likely value (MV), reflects the skewness of the distribution. The 90 percent lower- limit (LL) and upper-limit (UL) confidence estimates are $141 million and $191 million respectively. This means we are 90 percent sure that the present value of cash flows attributable to the 20 actual advances in applied technology is at least $141 million, and 90 percent sure that it is not more than $191 million. In other words, we are 80 percent confident that this total benefit is between $141 million and $191 million.

In the third stage of evaluation, the most-likely present value of cash flows attributable to the CANMET pit slope project for the 20 case studies is assessed at $41 million. This represents 24 percent of the stage two benefit attributable to the actual changes, and 18 percent of the total stage one value resulting from the changes.

The most-likely present value of cash flows attributable to the CANMET pit slope project for the individual cases are used to provide some initial breakdowns of results, before proceeding to consider the overall risk analysis assessment.

Of the estimated total benefit of $41 million, 73 percent has actually been realized up to and including 1982, while the remaining 27 percent is anticipated in the future. Thus, our results are much more an attempt to document past experience than to forecast what will happen in the future. Furthermore, as previously noted, even the future benefits are largely retrospective since they are extensions of actual changes already made and embodied in established operating practices.

The distribution of benefits among the case studies is highly skewed. Six cases show benefits greater than the average of approximately $2 million while the other 14 have below-average values. The distribution of benefits, ordered from highest to lowest, is illustrated in figure 13 and summarized in table 5.

Table 5

DISTRIBUTION OF BENEFITS AMONG CASE STUDIES

Number of Cases	Percentage of Cases	Percentage of Total Benefit
1	5	30
2	10	47
5	25	70
10	50	91
20	100	100

The geographic distribution of benefits is presented in table 6. British Columbia, Quebec, and Newfoundland realize the lion's share of the total benefit (93 percent combined). Nevertheless, the geographic spread of benefits is remarkably wide considering we are dealing here with only 20 case studies from 13 centres of mining activity.

Table 6

GEOGRAPHIC DISTRIBUTION OF BENEFITS

Region	Number of Cases	Percentage of Total Benefit
British Columbia	6	44
Quebec	4	30
Newfoundland	3	19
Manitoba	2	3
Ontario	4	2
Yukon	1	2

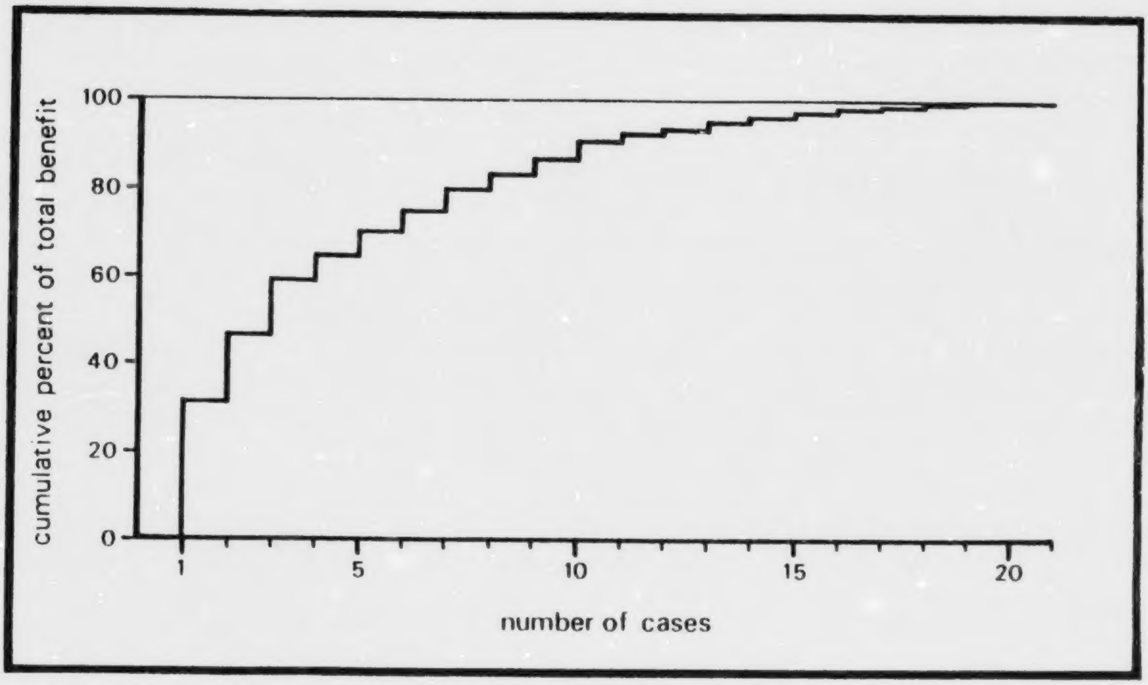

Figure 13. Distribution of Benefits Among Case Studies

The distribution of benefits by commodity type and mining method is shown in table 7. Most of the benefits are associated with open pit mining of metallic mineral deposits. While the cases are almost evenly split between nonferrous metal and iron mines, nonferrous metal operations account for a much higher share of the total benefit. These results no doubt reflect both the main focus of the CANMET project, and the areas of the mining industry where there has been the greatest scope for improving pit slope practices during the past decade.

Table 7

DISTRIBUTION OF BENEFITS BY COMMODITY TYPE AND MINING METHOD

Category	Number of Cases	Percentage of Total Benefit
Nonferrous metal open pit mines	9	62
Iron open pit mines	8	35
Other[a]	3	3

[a] asbestos open pit mine, underground nonferrous mine, government application.

The benefits realized as the direct result of the CANMET project are compared with those derived from the CANMET manual in table 8. It is perhaps rather surprising that the majority of the total benefit is directly related to the CANMET project itself, since the research and development phase was completed in 1977. This result no doubt reflects the high potential for improvement associated with the mining operations selected for attention in the CANMET project. It also could reflect adversely on the CANMET manual as a mechanism for technology transfer, a point we consider further in chapter 7.

Table 8

COMPARISON OF PROJECT-RELATED AND MANUAL-RELATED BENEFITS

Category	Number of Cases	Percentage of Total Benefit
Project-related cases	11	55
Manual-related cases	9	45

The above comparison of project-related and manual-related benefits closely parallels the distribution of case study benefits according to date of implementation as presented in table 9. Ten of the 11 case studies implemented in the 1975-78 period are directly related to the CANMET project while eight of the nine cases implemented during 1979-82 are related to the manual. These results suggest that the number of cases and their value have declined only modestly with time, showing perhaps that a relatively long period may be required to realize the potential benefits of technology transfer, and suggesting that the technology transfer is not yet complete.

Table 9

DISTRIBUTION OF BENEFITS BY DATE OF IMPLEMENTATION

Implementation Period	Number of Cases	Percentage of Total Benefit
1975-78	11	54
1979-82	9	46

The distribution of benefits according to the various components of the CANMET pit slope project is shown in table 10. Perimeter blasting is the only specialized area which can be singled out for attention, accounting for approximately one-third of the total benefit. Most of the other cases, classified as 'general', required a combination of two or more of the following components - structural geological information and analysis, groundwater studies, measurement of mechanical properties, pit slope design, installation of monitoring systems, and perimeter blasting. These general cases realize almost two-thirds of the total benefit, indicating the importance of integration and synthesis in advancing applied technology.

Table 10

DISTRIBUTION OF BENEFITS BY CANMET PROJECT COMPONENTS

Component	Number of Cases	Percentage of Total Benefit
General[a]	13	65
Perimeter blasting	5	34
Other[b]	2	1

[a] combination of structural geology, groundwater, mechanical properties, design, monitoring, and perimeter blasting components.

[b] mechanical support, waste embankments.

A breakdown of results by type of benefit is presented in table 11. A majority of cases concern reduction of waste excavation requirements and these account for a relatively large share of the total benefit. In these instances, an increase in overall mining productivity has resulted from the reduction in waste handling. While case study results indicate that the effect of advances in pit slope technology on increasing ore reserves is of much less significance, the outcome is likely biased by the fact that this is the most difficult type of benefit to quantify. The benefits associated with direct cost savings are relatively modest.

Table 11

DISTRIBUTION OF BENEFITS BY BENEFIT TYPE

Type	Number of Cases	Percentage of Total Benefit
Reduced waste excavation	12	86
Increased ore recovery	4	12
Lower direct mining costs	4	2

The risk analysis assessment for the stage three evaluation is presented in figure 14. The simulated probability distribution of possible present values for benefits attributable to the CANMET pit slope project bound the $41 million most-likely value which served as the basis for the foregoing breakdowns. The 80 percent confidence interval associated with this estimate is $33 to $46 million.

A cumulative probability distribution, obtained by summation of areas under the curve shown in figure 14, is applied in figure 15 to determine various confidence limits and intervals. These results, summarized in table 12 can be used to answer questions concerning the downside risk and upside potential associated with the total benefit assessed. For example, we are 90 percent sure that the total benefit attributable to the CANMET pit slope project is between $30 and $48 million but only 60 percent sure that it is between $35 and $44 million.

Table 12

CONFIDENCE LIMITS AND INTERVALS

Confidence Limit (percent)	Lower Limit (million $)	Upper Limit (million $)	Confidence Interval (percent)
95	30	48	90
90	33	46	80
80	35	44	60

The same cumulative distribution is used in figure 16 to determine probabilities of realizing particular levels of benefit. Of particular interest is the level of benefit which just equals the cost of the CANMET pit slope project, about $15 million. Summary results are presented in table 13.

These results can once again be applied to answer questions concerning insurable values for the total benefit assessed. For example, we are 99.9 percent sure that the total benefit is at least $20 million, there is a 54 percent chance of it being at least $40 million, but only a 3 percent chance of the total benefit exceeding $50 million. It is virtually certain that the total benefit at least equals the $15 million cost of the CANMET pit slope project.[34]

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[34] In this case, 'virtually certain' means more than 99.998 percent sure.

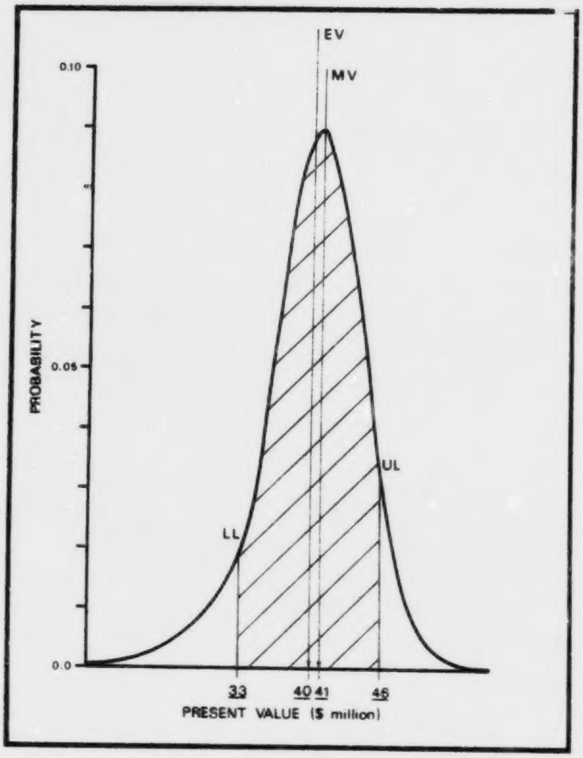

Figure 14.
Present Value of Cash Flows Attributable to CANMET Pit Slope Project

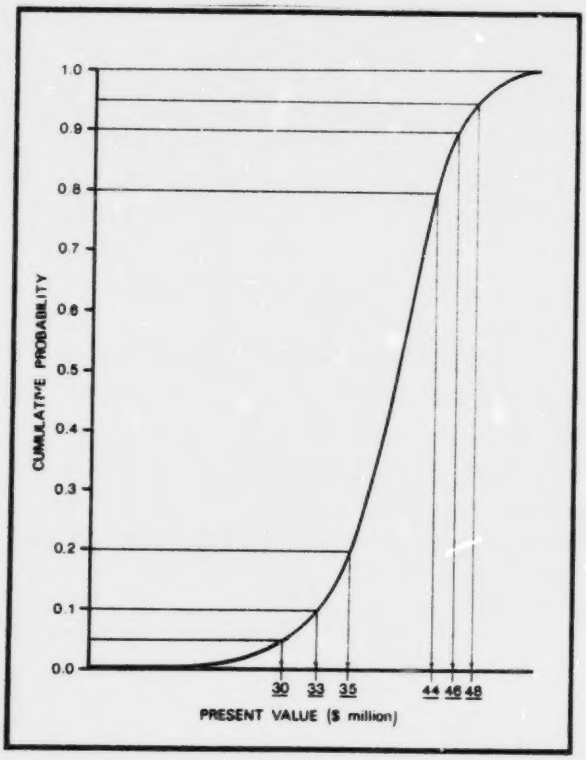

Figure 15.
Determining Confidence Limits and Intervals: Present Value of Cash Flows Attributable to the CANMET Pit Slope Project

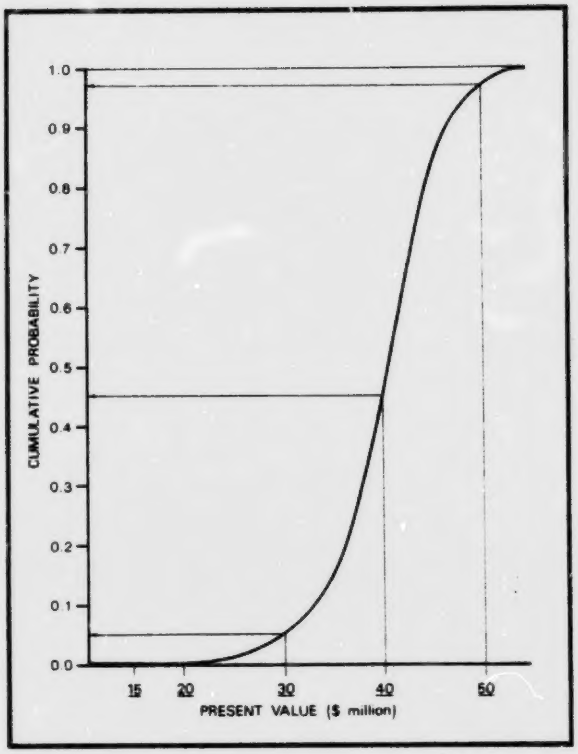

Figure 16.
Determining Probabilities of Realizing Particular Levels of Total Benefit: Present Value of Cash Flows Attributable to the CANMET Pit Slope Project

Table 13

PROBABILITIES OF REALIZING PARTICULAR LEVELS OF TOTAL BENEFIT

Minimum Total Benefit (million $)	Probability of Realizing Minimum Total Benefit
20	.999
30	.95
40	.54
50	.03

The quantitative results for the 20 specific case studies presented and analyzed here are used to give factual perspective to a broader spectrum of less tangible benefits which we now turn to examine.

Evaluation for the Nonferrous Mining Sector

Independently of the foregoing case study assessment, we have evaluated the potential benefits of advances in pit slope technology made during the past decade in the Canadian nonferrous mining sector and, within this framework, speculated on the benefits which could be attributed to the CANMET pit slope project. The data base, methodology, and results associated with this evaluation are described in appendix V. A brief overview is provided here.

The evaluation is based on a deposit-specific data base and methodology which has been developed at the Centre for Resource Studies. The deposit base consists of 80 actual nonferrous deposits in Canada amenable to open pit mining. These deposits are used to make a composite evaluation of the potential benefits of advances in pit slope technology.

Based on the wide range of actual data and expert opinions assembled in the course of the study, we first consider the increases in pit slope angle which could have resulted from advances achieved during the past decade. A most-likely average increase of 5 degrees in overall pit slope angle is estimated. The estimated increase is converted into a percentage reduction in average stripping ratio or, alternatively, a percentage increase in recoverable ore reserves. The increase in recoverable ore reserves variant is considered for both fixed and variable mine capacities.

Each open pit mine is evaluated with and without the estimated effects of advances in pit slope technology. Differences between the 'with' and 'without' scenarios are then used to assess the potential benefits associated with the advances, expressed as averages per deposit, and per tonne of ore mined, and then as a total for the nonferrous mining sector.

Preliminary analysis of results suggests that potential benefits might be drawn more or less evenly from reductions in waste excavation, increases in ore reserves while maintaining mine capacity, and increases in ore reserves leading to expansion of mine capacity. It is further assumed that present productive capacity in the nonferrous sector represents a long-term steady-state condition.

On these bases, a most-likely value of $619 million is assessed for the potential benefits of advances in pit slope technology made during the past decade in the Canadian nonferrous mining sector. This estimate is shown to be highly uncertain.

What part of this potential benefit might be attributable to the CANMET pit slope project? Considering the size of the CANMET project, its contribution to the literature on pit slope engineering described in chapter 3, the applications assessed in the case studies evaluated, and the wide range of uses of the project docmented in chapters 6 and 7, attribution of 10 percent of the potential benefits to the CANMET pit slope project seems to us to be quite reasonable.

Thus, a potential benefit of $62 million is attributable to the CANMET project. This benefit estimate includes both actual benefits which have been realized and prospective future benefits.

The potential benefit of $62 million compares with an attributable benefit of about $25 million for the nine nonferrous case studies documented. The difference between these two valuations is due partly to the fact that the nine cases represent only a part of the actual retrospective benefits, and partly to the prospective component of the potential benefit estimate. The high levels of uncertainty associated with these single-point assessments also should be kept in mind.

Direct Mining Industry Benefits and Benefit-Cost Ratio

Results from the case study assessment form the basis for evaluating the direct benefits attributable to the CANMET pit slope project which have been realized at established open pit operations in the Canadian mining industry. The scaling up of the case study assessment to the mining industry level considers the following three factors.

i Seven additional case studies, otherwise similar to those included in the case study assessment, were documented but could not be fully evaluated.

ii Mining industry benefits appear to be mainly restricted to metal mines. One asbestos mining case is included but, as discussed in chapters 6 and 7, we could find little in the way of actual changes associated with the CANMET project in coal, structural materials, tar sands, and other nonmetallic mineral operations.

iii The assessment of potential benefits for the nonferrous mining sector, summarized in the previous section, is also considered. The case study results suggest that about 60 percent of the benefits attributable to the CANMET pit slope project are associated with nonferrous open pit mines. If we further assume that 50 percent of the difference between the potential benefits and the actual case study benefits estimated for the nonferrous sector represent other actual retrospective benefits, the direct mining industry benefits attributable to the CANMET pit slope project would be:

$$\frac{25 + (.50)(62-25)}{.60} = \$72.5 \text{ million}^{35}$$

Considering these three factors, we conservatively estimate that the direct benefits attributable to the CANMET pit slope project which have been realized at Canadian open pit mining operations are 50 percent higher than the most-likely benefit for the 20 case studies, or $61.5 million.

Thus, the quantifiable benfit-cost ratio associated with the CANMET pit slope project is estimated to be:

$$\frac{61.5}{15.3} = \underline{4.0}$$

While the precise numbers estimated here are uncertain and debatable, their general magnitude gives a convincing message. Even considering only the twenty specific case studies, the benefits at least equal the cost of the project. Whether these benefits then scale up to a three, four, or five to one ratio is not very important. At a minimum, the CANMET pit slope project has paid for itself.

Finally, the effect of taxation on the direct benefit attributed to the CANMET project is evaluated. Given current Canadian mining taxation conditions, a tax rate of 43 percent would most likely apply to this benefit.[36] Thus, of the direct benefit of $61.5 million, about $35.0 million would be realized by the mining companies concerned in enhanced after-tax cash flows, and about $26.5 million would be collected by federal and provincial governments as increased tax revenues. In this way, governments indirectly benefit from the project.

Reconciliation of Actual Results with Original Project Justification

In terms of physical effects, we have reason to believe that the actual advances in pit slope technology which have occurred during the past decade are remarkably similar to those anticipated in the orginal justification of the CANMET pit slope project.

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[35] All values assessed and compared are once again in 1980 dollars at 1982.

[36] The tax conditions used are defined in Economic Effects of Smelter Controls on the Canadian Nonferrous Mining Industry, B.W. Mackenzie and M.L. Bilodeau, technical paper no. 2, Centre for Resource Studies, January 1982, appendix VIII, pp. 115-131.
The tax rate on these incremental benefits could vary through a wide range, 30 to 50 percent, depending on metal prices, and the province and company concerned.

Both the actual and envisaged changes have taken place mainly in the metallic mineral sector. In this sector, we estimate that a most-likely average increase of 3 degrees in pit slope angles has occurred during the past decade. This judgment is uncertain so we bound it with a possible range of steepenings of 1.5 degrees to 5 degrees.[37] These opinions are based on the broad spectrum of mine visits, interviews, and case study documentation carried out as part of this study, on actual results obtained, and on the informed judgments of geotechnical consultants.

As outlined in chapter 4, the original justification of the CANMET project included judgment that an appropriate research and development program would lead to a minimum average increase in pit slope angles of 2.5 degrees for approximately three-quarters of open pit production, and an expected average increase of 5 degrees for three-quarters of production. Thus, the improvement which was anticipated is somewhat less than what we judge to have actually occurred.

With respect to economic effects, the actual cost of the CANMET pit slope project, as assessed in chapter 4, is $15.3 million, expressed in 1980 dollars at 1982. The total estimated order-of-magnitude project cost in the original justification was $3.6 million. Assuming that this cost estimate is in constant 1971 dollars, and that the first year of the project was intended to be 1972, the envisaged time distribution of project costs is eqivalent to $15.0 million expressed in 1980 dollars at 1982.[38] Thus, the actual CANMET project cost was marginally (2 percent) higher than the original cost estimate.

In terms of economic benefits, both our assessment of actual benefits which have taken place and the predictions made in the original justification focus on direct benefits arising from improved slope design and control procedures at established open pit mines. Our evaluation of actual advances which have occurred produce a benefit-cost ratio of 4.0 attributable to the CANMET pit slope project. The uncertainty associated with this estimate is reflected by an estimated confidence range of 3.2 to 4.5. We regard this assessment as being 'conservative'.

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[37] These estimates compare with a most-likely value of 5 degrees and a range of 2 degrees to 10 degrees assessed in appendix V for the nonferrous sector. The differences reflect the fact that the iron ore sector, to date, has realized relatively modest overall improvements in pit slope angle.

[38] The money units and project starting date are not specified in the original justification. The planned schedule of expenditures is given in Coates and Dubnie, p. 11. The gross national expenditure implicit price index and an 8-percent cost of capital are applied, as in table 4 for the actual expenditures, to convert project costs to 1980 dollars at 1982.

The main evaluation considered in the original project justification was based on the effects of the 2.5 degree minimum average increase in slope angle anticipated. This results in a benefit-cost ratio of 6.6. The benefit-cost ratio associated with the 5 degree expected steepening is 13.2. These prospective assessments were based on the assumption of a 15-percent discount rate, and the assumption that the 1971 open pit production rate would continue.

If the time distributions of costs and benefits estimated in the original justification are discounted at 8 percent (as in our assessment of actual results) rather than at 15 percent, the anticipated benefit-cost ratio for the minimum improvement is 17.0, and the expected benefit-cost ratio is 34.0. The current open pit metal mine production rate in Canada is approximately 65 percent higher than the 1971 rate.[39] If the benefit streams projected in the original justification are adjusted as well for this higher rate of production, the minimum and expected benefit-cost ratios increase to 28.1 and 56.1 respectively.

What then explains the large difference in results between our actual assessment of benefit-cost ratios (3.2-4.5) and the prospective ratios estimated in the original justification (28.1-56.1)? The difference, we suggest, is due primarily to one important factor. The original justification appears to have considered the planned CANMET research and development program in isolation. Thus, it was implicitly assumed that the the total benefit arising from the projected technological advances was attributable to the CANMET project. In fact, we have found that the CANMET pit slope project has been a significant part, but only one part, of a large wave of advances in slope engineering and design which has swept across open pit mining during the past decade. Even in cases where the CANMET project has been applied, it is always only one of a number of practical components required to effect an improvement in pit slope angles and yield benefits.

As discussed earlier in this chapter, based on our study experience, it seems quite reasonable to attribute 10 percent of the potential benefits associated with advances in pit slope technology to the CANMET project. If this order-of-magnitude estimate is applied to the overall benefit-cost ratios evaluated in the original justification, minimum and expected benefit-cost ratios of 2.8 and 5.6, respectively, would be attributed to the CANMET project. These values are quite in line with our expected benefit-cost ratio of 4.0. We would expect the originally estimated benefit-cost ratios to be somewhat higher than our evaluation of actual results to date because they are based on potential benefits, whereas we have retrospectively focused on actual benefits. Study results indicate that technology transfer is not yet complete, and that there are further benefits still to be realized.

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[39] About 142.5 million tonnes of ore were produced from open pit metal mines in 1971 as compared to the current rate of approximately 233.5 million tonnes per year.

6. THE BROADER SPHERE OF BENEFITS

In this chapter, we consider the broader sphere of less tangible benefits attributable to the CANMET pit slope project, around the quantifiable core benefit of $61.5 million assessed in chapter 5. The benefits outlined here are based mainly on impressions arising from interviews conducted and responses to our questionnaires. A modest selection of the more interesting and focused comments from these sources is given in appendix VI.

Canadian Mining Industry

Established Mining Operations

A consensus exists that there was a definite need for the CANMET project and manual in the mid-seventies. New pit slope technology was being developed, and there was much scope for improvement in then-existing operating practices. A mechanism was required to put existing knowledge together in a form that would enable mine operators, not necessarily familiar with the subject of rock mechanics, to understand pit slope problems and opportunities and how to deal with them.

The pit slope project brought geotechnical consultants and mine operators together, thereby providing a conduit for technical exchange. Directly through this exchange, and indirectly through the Pit Slope Manual, managers at many Canadian mines became aware of geotechnical problems and procedures. The project encouraged mine managers to think about their rock slopes, moving away from traditional conventions towards a more rational design approach.

Thus, the CANMET pit slope project helped to create a general awareness in mine design, planning, operation, and management that pit slopes can be rationally designed and controlled through the application of engineering principles. While it is seldom possible to attribute specific improvements to this general awareness, there is little doubt that this intangible factor represents the single most important benefit of the CANMET project. In this respect, the project represents technology transfer in the form of continuing professional education.

Evidence suggests that the CANMET project has in fact encouraged a more quantitative approach to the design and analysis of pit slopes. The project's concept that a mine can design and live with pit slope failure has been generally accepted. In attempting to answer practical questions, the project has improved communications between mine operators and geotechnical consultants. It has also, in some cases, promoted the establishment of small in-house geotechnical groups. The CANMET project has also been of benefit in helping to provide a standard framework for information gathering and analysis procedures concerning pit slope design and control.

There is a general impression that the CANMET project has had a positive effect on achieving safer working conditions in open pit mines. The most important factor in this regard is the project's encouragement of the routine monitoring of open pit walls. This has helped to promote safety on the part of both management and unions.

While the focus of the CANMET project is of course on surface mining, we have also found evidence of its application in underground mines, including one of the case studies and several other instances. The blasting and monitoring aspects of the project appear to be most relevant in this regard.

With respect to more specific benefits, chapter 5 and appendix IV document 20 actual case studies in which the CANMET project has been applied. These cases provide the basis for assessing the direct benefits attributable to the CANMET pit slope project at established mining operations in Canada.

To the extent that the benefits quantified represent a reduction in direct mining cost, through reduced waste excavation, there would be a corresponding reduction in indirect mining costs. This reduction would be in the order of 20 percent to 50 percent of the direct cost savings.

The benefits realized at established mining operations have a ripple or multiplier effect in the Canadian economy, through their application as enhanced after-tax cash flows and increased federal and provincial tax revenues. A conservative income multiplier would be in the order of 2.0, meaning that, for each dollar of benefits realized at the mining operation, another two dollars of benefits are created through the effect of that dollar elsewhere in the economy.

The direct benefits attributable to the CANMET pit slope project also result in improvements in foreign exchange earnings, employment, and regional development opportunities. We have not attempted to quantify any of these more general indirect benefits, which must be substantial.

Despite the considerable advances in pit slope design and control which have already taken place during the past decade, evidence indicates that there are important potential benefits yet to be realized. Individual mining operations appear to be at quite different stages of awareness regarding pit slope engineering. At some operations, applications are well advanced and accepted as standard practice. At others, engineers are still in the process of convincing managers of the benefits of slope stability analysis. At yet other mines, pit slopes are still not regarded as important to mine planning. For example, the traditional

45-degree slope convention is followed, with no perception of benefits associated with improved slope information and analysis techniques. In some instances, problems associated with deep workings and final pit walls have not yet been encountered. Unfortunately, a few mine operators appear to pride themselves on their ignorance of modern rational engineering practices. In any case, there is little doubt that the potential future benefits associated with the CANMET pit slope project are considerable. This view is supported by the time distribution of case study benefits evaluated in chapter 5 (table 9).

A number of benefit barriers have been encountered with respect to the transfer of pit slope technology to different types of mining operations. The benefits resulting from the CANMET project appear to have been restricted mainly to the metallic mineral sector: nonferrous metal mines and iron ore operations (table 7).

Asbestos mining is the subject of one of the case studies, as well as of another case which was documented but could not be fully evaluated. Asbestos open pits tend to be relatively mature and production in the sector is generally declining. Consequently, slope stability problems were encountered from an early date, prior to the start of the CANMET project. In fact, the largest and most dramatic pit slope failure on record in Canada occurred at an asbestos pit in 1970.[40] The CANMET project came too late to assist with the solution of such problems.

We have found little evidence of the CANMET project being applied in the design of quarrying operations for structural materials. It would appear that the characteristics of these operations - the flat-bedded nature of deposits, shallow mining depths, normally vertical walls, and low unit costs - give rise to a different set of technological and economic conditions than dealt with in the Pit Slope Manual.

Strip coal mines and tar sands operations are an important and rapidly growing part of the Canadian mining industry as outlined in chapter 3. While we have found a few instances where the CANMET manual has been applied in coal operations, there is a strong feeling that the characteristics of coal mines are generally sufficiently different to preclude application of the Pit Slope Manual. The implications of this finding are considered in chapter 7.

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40. From correspondence between federal and provincial governments at that time, it would appear that this event had some influence on the formulation of the CANMET pit slope project.

New Mine Development Opportunities

New open pit mine development opportunities represent mine replacement and growth prospects beyond the productive capability of established mining operations. While the Canadian mining industry is currently operating so far below existing capacity that it is difficult to contemplate much in the way of new open pit developments[41], there should in fact be good opportunities for expansion beyond 1985.

Potential for new mine development certainly exists when market conditions provide the necessary economic justification. For example, appendix V cites 45 potentially economic but presently undeveloped nonferrous deposits amenable, at least in part, to open pit mining. The advances in pit slope technology achieved during the past decade enhance the economic value, and improve the development prospects, for each of these potential mines. For example, the assessment carried out in appendix V for the nonferrous sector indicates that the average improvement would most likely be in the order of $19 million per mine in terms of before-tax net present value at the start of development (table 17). Thus, an increase in slope angles enabled by technological advances, including application of the Pit Slope Manual, may provide justification for the development of mineral deposits which otherwise would have remained uneconomic.

Another relevant example is the case of high-grade uranium deposits in northern Saskatchewan. Here, environmental risks preclude underground mining. Hundreds of millions of dollars in pre-production waste stripping costs are required to expose each of these deposits for open pit mining. Under these circumstances, the economic benefits of steeper slope angles, made possible by the application of technological advances realized during the past decade, are potentially very large in terms of both lower capital costs and a shorter development period.

It is extremely difficult to attribute a part of these benefits to new mine development opportunities to the CANMET project. There is some limited evidence that the Pit Slope Manual is being used in feasibility studies for potential new mine developments. However, unlike operating mines, where changes are incremetal and their effects, therefore, can be isolated, the purpose of feasibility studies is to integrate all elements into an overall deposit design, planning, and decision process. A further difficulty is that these potential developments are prospective. We do not actually know when new mines will be developed and what benefits will actually be realized. Thus, in these cases it has not been practical to quantify the benefits attributable to the CANMET project.

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[41] The only exception being coal mines.

For new mine development opportunities, the benefits attributable to the CANMET project are realized through technology transfer directly from the manual, by geotechnical consultants who benefited as a result of the contracting-out process, by university graduates who have been exposed to the manual as part of their education, and through technical literature which describes design procedures emanating from the CANMET project.

Longer-Term Mineral Supply

The advances in pit slope technology which have taken place during the past decade have a broader, longer-term impact on the value of mineral endowment in Canada and the economic characteristics of our mineral supply process. These longer-term benefits, beyond current operations and known development prospects, include:

i a greater number of economic discoveries justifying development;
ii a higher potential value of mineral supply for Canadian society;
iii an improved investment incentive for mining companies to explore for economic mineral deposits;
iv an increase in direct employment in the mining sector;
v higher provincial and federal government tax revenues.

We have in fact carried out such a long-term assessment for the Canadian nonferrous mining sector, 'with' and 'without' the advances in pit slope technology realized during the past decade, to show the incremental benefits associated with these changes. These results indicate a significant enhancement of nonferrous mineral endowment values in terms of the types of benefit outlined above.

Government Regulation

Prior to 1972, almost all provinces required 45-degree pit slopes and defined berm dimensions beyond specified minimum mining depths. Since that time, new mining regulations and changes in the interpretation of regulations have generally been introduced either to require or to permit the engineering of pit slopes. Associated with these regulatory changes, positions for geotechnical specialists have been established in a number of mine inspectorates.

These changes in government mining regulations and practices have been encouraged by the Pit Slope Manual. The manual has been used to give regulatory authorities confidence in allowing steeper pit slopes, and convincing them of the merits of more flexible regulations.

All mine inspectors contacted during the study who worked in jurisdictions with open pit mines were aware of and in some way made use of the Pit Slope Manual. If an open pit operation follows the procedures recommended in the CANMET manual, the work is usually accepted by mine inspectors as being good engineering practice. Mine inspectors generally feel that the manual has had a positive effect on achieving safer working conditions in open pit mines.

In several instances, including one of the case studies documented in chapter 5, the manual has contributed to the development of codes of conduct for open pit mines and, more generally, for tailings and waste rock disposal.

Thus, significant benefits have been associated with application of the Pit Slope Manual for government regulation. These benefits are offset to some extent by the increased costs to both governments and mining companies of administering the more flexible and detailed mining regulations which have resulted.

Geotechnical Consultants

There is little doubt that the contracting-out process used for the CANMET pit slope project made an important contribution to the development of geotechnical consulting capability in Canada. Twenty-four contracts were awarded to consulting firms and, of these, 21 were given to consultants based in Canada. The CANMET project was, in general, very beneficial to these consultants in terms of recognition, knowledge, and capability. It stimulated the growth of their consulting practices, both domestically and internationally. The procedures and analytical techniques presently used by these firms are attributable in part to their involvement in the research and development phase of the CANMET project. We found that these benefits were freely acknowledged by most of the consultants interviewed. In one or two instances, there were suggestions that the contracting-out process mainly resulted in the sale of off-the-shelf material. If this is indeed so, these firms would not have shared in the above benefits.

In a few cases, we also found evidence of geotechnical consultants who were not involved in the CANMET project who benefit from application of specialized techniques and procedures described in the Pit Slope Manual.

More generally, the growth of geotechnical consulting capability in Canada was indirectly stimulated by the CANMET project. The main purpose of the project was to develop an awareness of and capability for pit slope engineering at operating mines. As previously described, this in fact occurred, but at the same time the CANMET project also created higher levels of demand for geotechnical consulting services. This is confirmed by comments from mine operators regarding the increasing use of consultants, in balance with the development of their own in-house geotechnical skills. Changes in government regulations have further stimulated this demand; for example, some jurisdictions now require that pit slope design at the feasibility study stage be done by consultants.

To provide an overview of the growth of geotechnical consultants in Canada, we have made an order-of-magnitude survey of the seven Canadian firms that are most highly specialized in rock mechanics as applied to open pit and underground mining, including tailings and waste disposal, and routine testwork. Five of these firms existed in 1972, and four were involved in the CANMET project as contractors. We estimate that in 1972 these firms employed 30 professionals and 70 total staff, and would have generated annual billings totalling about $2 million. The seven firms surveyed in 1982 are estimated to comprise 157 professionals and 317 total staff, with annual billings totalling approximately $11 million, of which $1.5 million is for work conducted outside of Canada.

This illustration of the growth of geotechnical consulting firms in Canada of course reflects the overall advances in pit slope technology which have taken place during the past decade. However, we think that it is not unreasonable to attribute 25 percent of this growth, and the associated benefits, to the CANMET pit slope project.

University Education

Evidence indicates that all undergraduate mining engineering students at Canadian universities are exposed in some way to the Pit Slope Manual. This exposure is usually as a general reference and basis for laboratory work in rock mechanics and blasting courses, and sometimes as a reference for mine design studies. The students' contact with the manual is normally highly selective, in some instances relating to aspects of the CANMET project in which the staff member concerned had been directly involved. Nevertheless, mining engineers graduating today are aware of the existence of the Pit Slope Manual, and are sufficiently well versed in its contents to know when it should be consulted.

Graduate students in mining engineering, particularly those specializing in rock mechanics, receive a more complete and intensive exposure to the CANMET manual. The manual is generally used as a required reference in graduate courses in rock mechanics.

Undergraduate students taking geotechnical options in geological engineering or geological sciences programs are familiarized with the Pit Slope Manual in much the same way as undergraduate mining engineers. However, the emphasis is usually specifically on structural geological information and analysis.

We could find little evidence of the manual's use in civil engineering programs. This may not be very meaningful because the response to questionnaires from contacts identified in civil engineering departments was disappointing.

Open Pit Suppliers

We were unable to obtain substantive information concerning the benefit of the CANMET project to open pit suppliers. Effects appear to include demand for small specialized drilling units for perimeter blasting, pit wall control monitoring systems, and computer software for the analysis of geological, rock strength, and groundwater information, and for slope design. We do not think these benefits are of major importance in the overall context of our study.

Civil Engineering Construction

One of the original ideas underlying the CANMET project was to adapt civil engineering design practices to the requirements of open pit mining. The process does not appear to be reversible. We have been able to find only a few specialized cases where the Pit Slope Manual is used in civil engineering construction.

Large capital-intensive civil construction projects have, for a long time, been intensively engineered - much more so than open pit mines. This trend continues today. Also, the design of rock slopes in civil engineering is based on the factor-of-safety approach described in chapter 3. Several civil engineers have commented that the probabilistic 'reliability analysis' approach applied in the Pit Slope Manual is not suited to the design of rock slopes in civil engineering construction.

International Spillovers

Despite our very limited international coverage, we received a strong response. It appears that the Pit Slope Manual is well known internationally, particularly in the United States, Australia, South Africa, and the United Kingdom. In these countries, the manual has been used by mine operators, geotechnical consultants, government regulators, and university-based mining engineers. Technology transfer has been accomplished mainly by use of the manual. In some cases, interest has been stimulated by the foreign business activities of Canadian geotechnical consultants. Comments are generally very favourable, as indicated by those included in appendix VI. We would be surprised if the international benefits attributable to the Pit Slope Manual did not at least match those which have been realized in Canada.

7. PROJECT, MANUAL, AND TECHNOLOGY TRANSFER CRITIQUE

Finally, in this last chapter we comment on the implementation, structure and conduct of the research and development phase of the CANMET pit slope project; evaluate the Pit Slope Manual; examine the technology transfer mechanisms used; and appraise the technical and economic merits of the project. The summary views expressed here are generalized from a large number and wide range of interview and questionnaire responses. A relatively small selection of representative comments from these sources is documented in appendix VII.

Project Implementation and Scope

The CANMET project was well conceived in both technical and economic terms. The evidence assembled in this study leaves little doubt that it was the single most worthwhile mining research and development project for Canada to undertake in the seventies.

The scope of work for the research and development phase was to prepare an engineering manual for the design of open pit slopes. This required the application and integration of existing engineering principles and knowledge across several disciplines. The purpose of the project was to encourage open pit mine operators in Canada to develop a capability for the rational design of pit slopes.

In the early stages of project formulation and implementation, there is an impression that ideas and input were contributed mainly by government personnel, consultants, and university staff. For some reason, open pit mine operators and managers did not participate to the same extent. It appears in retrospect that the mining industry should have had a larger role.

Given the purpose of the CANMET project, the support of major mining companies should have been secured from the start, and a mechanism should have been established for their continuing input into project management as the research and development progressed. It would have been best if the demand for the pit slope project had come directly from the mining industry and, if not forthcoming, this demand should have been stimulated. Under the circumstances existing at that time, such stimulation should not have been too difficult.

A fuller involvement of the mining industry in project implementation would, we believe, have significantly increased the potential for participation of mining operations in the research and development phase, and for the acceptance and application of the manual. Project concepts would have been more fully circulated among the potential users of the project. In this way, the manual itself would perhaps have been more closely tailored to the needs of the mine operators who have to put it to work.

Project Structure: the Contracting-Out Process

There were various ways in which the CANMET project could at least in theory have been structured. The government could have conducted the study in house. Perhaps it could have been contracted to a single consulting firm. However, given the wide range of expertise required, the best practical solution was no doubt to contract out most of the research and development work to a large number of private sector and university organizations. This in fact is what was done.

While the contracting-out process was dictated by the research and development requirements of the project, this structure has in fact been responsible for realization of a substantial share of the total benefits attributable to the CANMET project. This is illustrated by the breakdown of case study results into project-related and manual-related benefits. Even though the research and development phase was completed in 1977, 55 percent of the case study benefits is directly related to the project itself. This point is confirmed by more general comments received.[42] Futhermore, as outlined in chapter 6, the contracting-out process has generated important benefits with regard to the development of geotechnical consulting capability in Canada. Thus, contracting out has been an important mechanism for technology transfer in the CANMET pit slope project.

Some generally negative views have been expressed concerning the behaviour of contractors, particularly geotechnical consultants, involved in the project. These include concerns about self-promotion, biased opinions on controversial concepts, lack of required expertise, and the use of already existing material. However, an internal government review of the research and development performance associated with the contracting-out process for the CANMET project, found that the level of unacceptable performances was not excessive. Commentary on the reasons for poor contract performance is included in this review.[43]

The project-related case study benefits cited above have resulted primarily from the direct participation of mining companies in the project and from the direct involvement of CANMET personnel at the mining operations concerned. Technology transfer from the CANMET project to the mining operation, in the cases we have been able to document, has not been primarily related to the geotechnical consultants involved. Thus, in retrospect, it appears that a more balanced allocation of project funds among government, mine operators, and consulting firms might have enhanced the direct benefits generated by the project. This would have enabled a larger number of mine operators to participate in the project, encouraged more personal contact of CANMET staff with open pit mines, and placed less emphasis on geotechnical consultants. For example, we believe that more balance between the 9 contracts awarded to mining companies and the 24 contracts awarded to consultants would have been beneficial. There has been no criticism, incidentally, of the roles of universities and non-profit research councils in the research and development work.

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[42] See selected comments on 'Technology Transfer', appendix VII.

[43] See Pit Slope Project - a Case of Contracting Out, G. Bartlett and D.F. Coates, CANMET Report 78-17, September 1978. A summary of results is provided under 'The Contracting-Out Process', appendix VII.

The broad scope of the CANMET project and the contracting-out process adopted made control and coordination difficult. Under these circumstances, CANMET's performance in managing the project was commended by several respondents. On the other hand, a number of negative views were also expressed: too many people and organizations involved; the need to have government personnel coordinating the technical work rather than solely participating in a 'clearing house' at the management level; inadequate flexibility and poor communications, resulting in industry alienation and lost project benefits; a frustrating editing process for preparing the manual for publication; and the lack of integration in the final manual product. Relating to these views are comments to the effect that the cost of the CANMET project was too high for the work which was actually performed. These factors suggest that the contracting-out structure, at the least in this case, is a somewhat inefficient and relatively costly process. However, these disadvantages should be balanced against the technology transfer benefits associated with the process.

Project Philosophy

We think that the probabilistic 'reliability analysis' philosophy which underlies the CANMET project is conceptually and analytically enlightened. However, the presentation of this philosophy in the Pit Slope Manual is strongly criticized as being unnecessarily complex and academic, and has seriously detracted from the value of the manual. The design philosophy should have been introduced in simple common sense terms as a logical extension of the traditional factor-of-safety approach to pit slope design. It would have been beneficial to include both approaches, evaluating their relative strengths and weaknesses, and emphasizing the convertibility between them. In fact, it is clear that that the exaggerated complexity of the philosophy's presentation works against the manual's purpose of providing a practical working tool for mine operators.

The Pit Slope Manual

There was a definite need for the Pit Slope Manual at the time of its publication, and there still is. Although the manual includes little in the way of new or unique knowledge, by integrating relevant existing technologies related to pit slope engineering it has made a significant contribution to the state of the art for pit slope design and control in Canada. The manual provides a means for mine operators in remote locations, not necessarily familiar with rock mechanics, to understand their pit slope problems and opportunities, and how to deal with them. Thus, the manual represents new knowledge in the hands of these mining industry users.

Widespread use of the Pit Slope Manual is evident, and is confirmed by comments included in appendices VI and VII. The main competitor in the field is Rock Slope Engineering by Hoek and Bray. While the two texts have similar purposes, their approach to the subject and structure are very different. Strong views are expressed on the relative merits of these publications but there appears to be no overall consensus on which is preferred. Both have made lasting contributions to the advancement of pit slope technology.

In 1979, the Canadian National Committee on Rock Mechanics conducted a questionnaire survey of users concerning the Pit Slope Manual.[44] A summary of the responses, included in appendix I, is generally consistent with the comments we have gathered.

It is difficult to determine a consensus from the wide range of views expressed on the individual chapters of the Pit Slope Manual. However, the structural geology, groundwater, and perimeter blasting chapters are considered to have worked best in practice. The analysis of case study results in chapter 5 indicates that perimeter blasting is the only specialized area which can be singled out for special attention, accounting for approximately one-third of the total benefit assessed.

The monitoring chapter and particularly the design chapter are most heavily criticized. This is unfortunate, because both of these topics are deemed to have high potential value. The introduction of slope monitoring systems at open pit mines in Canada is one of the most widespread and beneficial advances made in recent years. The design chapter is potentially the most important in the manual, integrating the information components required for pit slope analysis. Furthermore, our case study results illustrate the key role of integration and synthesis in advancing pit slope technology.

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[44] See 'Report of the Sub-Committee on Rock Slopes', Canadian National Committee on Rock Mechanics, Toronto, May 1980.

The Pit Slope Manual reflects state-of-the-art technology circa 1975. Thus, there are opportunity costs associated with the manual's use in 1983 and beyond. If the manual is to play a future role in Canadian pit slope design, it needs to be selectively revised, updated and extended. Potential future benefits from advances in pit slope engineering, outlined in chapter 6, provide justification for this further work.

Comments indicate that the monitoring, design, and perimeter blasting chapters have the highest priority for revision. Apparently, the monitoring and perimeter blasting chapters have already been revised but not yet published.

More generally, there is a strong feeling that the Pit Slope Manual is in need of simplification and condensation, preferably into a single volume. A comprehensive index is required. The computer programs included have been widely criticized, and should be corrected, simplified, updated, and made more user oriented. The 'expensive' design approach which the manual is perceived to advocate should be balanced by consideration of lower-cost alternatives.

Regarding possible extension of the manual, the two areas of greatest interest and highest potential appear to be:

i inclusion of detailed case studies with practical solutions;
ii attention to slope stability concerns for coal mine operators, particularly for conditions existing in western Canada.

Our overall impression is that the benefits realized from the Pit Slope Manual are disappointing in relation to the potential which did and still does exist.

Technology Transfer

The CANMET pit slope project is essentially an opportunity for technology transfer, from government, universities, and consulting firms to the Canadian mining industry. This study evaluates the strengths and weaknesses of that technology transfer process.

We have already analyzed the major benefits which were realized in the research and development phase of the project and suggested how these could of been enhanced by a greater balance among the government, mining company, and consulting inputs. In general, however, contracting out has proven to be a successful means of technology transfer.

The prevailing view is that the Pit Slope Manual transfers technology to open pit mining practice cheaply and extensively. However, as outlined above, the manual needs to be revised, updated and extended. Furthermore, the manual is only one element of the technology transfer process. There is also a critical need for more intensive on-going mechanisms.

Practical problems seem to have arisen with the CANMET project when the research and development phase was completed and the project team disbanded. A few seminars were conducted at the beginning of the 1977-81 technology transfer phase. Audio-visual packages highlighting the manual and its use were prepared and sent on request to several companies. There is a strong correlation between the engineering personnel and mining operations represented at the seminars and the manual-related benefits which have been realized. Unfortunately, the technology transfer effort appears to have ended in 1978. We think this was because, despite the planned five-year technology transfer phase, the focus of the CANMET project turned to production of the manual rather than the transfer of technology. When the manual was completed, the technology transfer effort soon dissipated. This, we believe, has been an important impedement to realization of potential project benefits.

The general feeling expressed in comments received is that the technology transfer phase should have included all of the following elements on a modest but on-going basis:

i seminars and training programs;
ii selected mine visits by CANMET personnel;
iii availability of a resource person at CANMET for mine operators to contact for advice;
iv updating, revision, and extension of the manual and associated audio-visual packages.

Comments indicate that personal contact is essential to the transfer of technology, and that there is a critical need for more contact by CANMET personnel in the real world of Canadian mining operations.

Considerable potential remains for improvement in current pit slope design and control practices. Our case study results indicate that the time stream of benefits attributable to the CANMET project has declined only modestly during the period 1975-82. About 20 percent of the nonferrous mining operations visited and interviewed are judged to have major potential for improvement, based on present slope engineering procedures. There appear to be more widespread opportunities for technological advances in iron ore and coal mining.

Therefore, we recommend that consideration be given to reinstituting the technology transfer phase of the CANMET project abandoned in 1978. This new thrust could evolve from the revisions of the Pit Slope Manual which apparently are already in progess. However, it is vital that the technology transfer program be comprehensive, embodying all four elements cited above.

The suggested technology transfer program should be low-profile and low-cost, utilizing existing CANMET personnel. A budget of not more than $150,000 per year might be considered for the incremental costs associated with seminars and workshops, liaison with mining operations, manual revisions and extensions, and publishing. An on-going five year commitment should be made to sustain the program.

There is a general awareness from this study that advances in pit slope technology, particularly the more important ones, require a rather improbable combination of circumstances: initiative and awareness of engineering staff regarding the potential for improvement; concepts and confidence to implement change arising from the advice of consultants and government experts; communications, justification, and support from mine management. Mineral technology transfer and application is certainly not a fast, continuous, pervasive process. Rather, it occurs once in a while when a set of unusually favourable circumstances combine. Furthermore, as our case studies illustrate, it often takes several years to bring an opportunity for technological advance to the point of implementation.

Technical and Economic Merits

As discussed in this chapter, there are important lessons to be learned from the CANMET pit slope project. These should help provide an improved basis for directing mining research and development funds along lines which are most beneficial to the productive capability and competitiveness of the mineral sector in Canada. The pit slope project experience should also help establish guidelines for planning future government-industry research initiatives.

Despite the practical limitations of the CANMET pit slope project, our study confirms its technical and economic merits. The project has made an important contribution to the difficult process of mineral technology transfer. The bottom line is that, in retrospect, the CANMET pit slope project is economically justified for the federal government, the mining industry, and Canadian society.

REFERENCES

Baker, N. and J. Freeland, 'Recent Advances in R & D Benefit Measurement and Project Selection Methods', Management Science, v. 21, n. 10, June 1975.

Barrett, D., 'Productivity Programs: Nuturing the Climate for Creativity and Innovation', Business Quarterly, University of Western Ontario, Autumn 1981.

Bartlett, G. and D.F. Coates, Pit Slope Project - a Case Study of Contracting-Out, CANMET Report 78-17, September 1978.

Betz, F., et al., 'Allocating R & D Resources in the Public Sector', pp. 235-252 in Management of Research and Innovation, B.V. Dean and J.L. Goldhar (eds.), North-Holland Publishing, 1980.

Brawner, C.O. (editor), Stability in Surface Mining, American Institute of Mining Engineers, New York, 1982, 872 p.

Brawner, C.O. and V. Milligan (editors), Stability in Open Pit Mining, American Institute of Mining Engineers, New York, 1971, 242 p.

Brawner, C.O. and V. Milligan (editors), Geotechnical Practice for Stability in Open Pit Mining, American Institute of Mining Engineers, New York, 1972, 274 p.

Coates, D.F., Elements of Planning Affecting Rock Slope Design for Open Pit Mines, MR-71/77-LD, Internal Report, Mining Research Centre, Department of Energy, Mines and Resources, July 1971.

Coates, D.F., Rock Mechanics Principles, Monograph 874, CANMET, Energy, Mines and Resources Canada, 1981.

Coates, D.F. and A. Dubnie, Benefits and Costs of Research on Rock Slopes, MR71/50-ID, Internal Report, Mining Research Centre, Department of Energy, Mines and Resources, May 1971.

Commission of the European Communities, Science and Technology Policy: the Evaluation of Research and Development, EUR 6346, 1978.

Cordell, A. and J. Gilmour, The Role and Function of Government Laboratories and the Transfer of Technology to the Manufacturing Sector, Background Study No. 35, Science Council of Canada, 1976.

Energy, Mines and Resources Canada, Pit Slope Manual, 10 chapters with supplements, 27 volumes, CANMET, 1976 and 1977.

Energy, Mines and Resources Canada, Mineral Policy: a Discussion Paper, December 1981, 157 p.

Gannicott, K., 'The Management and Administration of Government Research and Development', Australian Journal of Public Administration, December 1979.

Henriquez, L.N., An Assessment Framework for Mineral Research and Development: the Case of the Canada Centre for Mineral and Energy Technology, unpublished Ph.D. thesis, McGill University, February 1979, 176 p.

Hoek, E. and J.W. Bray, Rock Slope Engineering, Institution of Mining and Metallurgy, London, revised third edition, 1981, 358 p.

Lamontagne, M., A Science Policy for Canada, Report of the Senate Special Committee on Science Policy, Ottawa, 1972.

Martin, M.J.C., et al., Transfer of Technology from Government Laboratories to Industry, School of Business Administration, Dalhousie University, November 1978.

Mishan, E.J., Cost-Benefit Analysis, Allen and Unwin, London, second edition, 1975.

Morrison, R.G.K., A Philosophy of Ground Control, McGill University, 1976, 182 p.

Pavitt, K. and W. Walker, 'Government Policies Towards Industrial Innovation: a Review', Research Policy, 1976.

Richardson P., et al., The Role of Innovation in the Mining and Mining Supply Industries, Mineral Bulletin MR 146, Department of Energy, Mines and Resources, Ottawa, 1976.

Rosenberg, N. (editor), The Economics of Technological Change, Penguin Books, 1971.

Sprague, J., A Method of Measuring the Costs and Benefits of Applied Research, Information Circular 8414, Bureau of Mines, U.S. Department of the Interior, 1969.

Stewart, R.M. and B.A. Kennedy, 'The Role of Slope Stability in the Economics, Design and Operation of Open Pit Mines', pp. 5-21 in Stability in Open Pit Mining, C.O. Brawner and V. Milligan (editors), American Institute of Mining Engineers, New York, 1971, 242 p.

Treasury Board, Benefit-Cost Analysis Guide, Ottawa, March 1976.

APPENDIX I

INTERVIEW CHECKLISTS

CHECKLIST FOR OPEN PIT MINE OPERATORS

Date:

MINE: ______________________________

Interviews (name, position):

- focus year by year on 1972-81 period.

INTRODUCTION

- key people involved 1972-81
  - mine managers
  - chief mine engineers
  - geotechnical engineers
  - consultants
- individual pits developed and operated during period; dates of feasibility studies, mine design studies
- evolution of geotechnical group;
  - number of engineers and technicians
- evolution of government inspection/regulation
- awareness of CANMET pit slope project?
  - from what date
  - how
    - case study for project
    - manual
    - CANMET seminars
    - consultants
    - new graduates
- could the technology have been transferred more quickly/effectively?
- geology of each pit
- when did each pit start to be classified into domains and how has this classification evolved?
- definition of domains for each pit

PIT PROFILES (see attached pit profile form)

- ore removed by year
- waste removed by year

} stripping ratio

- cut-off grade for long-term planning
- ore reserves
  - tonnage and average grades
- actual pit depth
- ultimate planned pit depth
- range of overall slope angles and average overall slope angles for pit and within each domain as these have been defined (see slope geometry form attached)

- berm width
- bench height
- bench face angle

} intermediate angle

- number and width of haul roads (on cross section)
- frequency of pit slides
  - volume of material
  - significance to operations
    - delays and disruptions
- unit operating costs
  - ore delivered to mill
  - waste delivered to dump
- geotechnical costs
- costs of slide cleanup
- projected future profile of pit over remaining life based on current planning

MAJOR CHANGES IN PIT SLOPE DESIGN, PLANNING AND OPERATION

- dates of major changes

- classification of changes
  - improved information base and analysis
    - structural geology
    - mechanical properties
    - groundwater conditions
  - feasibility and design studies for new pits
  - improved slope design for existing pits
  - improved support systems
    - monitoring
    - perimeter blasting
    - mechnical support
  - improved waste and tailings embankments
  - other

- in each case:
  - how did the idea for change originate?
    - management
    - engineering staff
    - geotechnical staff
    - consultants
    - other
  - key people involved in analyzing effects of change; documentation in reports
  - alternatives considered; decision made
  - implementation of decision

- anticipated costs and benefits of change
  - costs
    - capital and operating
    - time distribution
  - benefits
    - slope angle changes: plus or minus
    - waste removed per year
    - stripping ratio
    - frequency of failure
    - cut-off grade and ore reserves
    - ultimate pit depth

- actual costs and benefits of change
  - classify as for 'anticipated costs and benefits' above

- were any of these changes related to:
  - CANMET pit slope project?
  - CANMET pit slope manual?

- if so, what specific aspects of the CANMET work were applied? (see attached case study form)

- if so, what explains the awareness of the CANMET work?
  - management/engineering staff
  - case study for project
  - manual
  - CANMET seminars
  - consultants
  - new graduates

- subjective estimate of percent range of actual costs and benefits which could be reasonably attributable to the pit slope project and manual

  e.g. 10-15 percent
  25-30 percent

PIT SLOPE MANUAL

- how often is it used; when did it start being used?
- is it being used more or less frequently with time?
- what parts have been used; for what purpose?
- what parts have not been used; why not?
  - too complex/sophisticated
  - irrelevant, etc.
- have the associated computer programs been used - when, for what, which ones, usefulness?
- is the manual in need of:
  - updating
  - revision
  - extension
  - simplification

  } which parts?
- is the manual itself a useful way to transfer technology to open pit mining practice?
  - if not, why not?
- what other manuals/references of this type do you use?
  - how do they compare with CANMET manual?
- have you used the CANMET audio-visual packages on the manual?
  - if so, have they been useful?
- could the CANMET manual be usefully supported by seminars, training programs, etc.?

PIT PROFILE

		1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	FUTURE
1.	Ore removed per year (million tons)											
2.	Waste removed per year (million tons)											
3.	Planned ore reserves (tonnage)											
4.	Cut-off grade											
5.	Pit depth											
6.	Overall slope angles Inter ramp slope angles											
7.	Frequency of pit slides (number per year)											
8.	Average volume of slide (document larger ones)											
9.	Ore haulage costs											
10.	Waste haulage costs											
11.	Cost of ton of ore left in ground— Average grade											
12.	Geotechnical budget											
13.	Cost of slide clean up											
	Other - specify ________											

SLOPE GEOMETRY

*Year ________

		SECTOR 1	SECTOR 2	SECTOR 3	SECTOR 4	SECTOR 5	SECTOR 6	SECTOR 7
1.	Location e.g. North Wall							
2.	Pit Depth							
3.	Wall Length							
4.	Overall Wall Angle							
	Inter-Ramp Wall Angle							
5.	Bench Height							
6.	Bench Width							
7.	Bench Face Angle							
8.	Number of Haul Roads							

* Year when major design changes incurred

Benefits of Change

Cost of Study

Has the Pit Slope Manual Contributed: - circle as applicable

1. No contribution to above
2. 0-20% contribution
3. 20-40% contribution
4. 40-60% contribution
5. 60-80% contribution
6. 80-100% contribution.

CASE STUDY

MINE ____

LOCATION OF SLIDE (RELATIVE TO OPERATION) ____________________

____

VOLUME OF SLIDE ____

____

GEOLOGY OF SLIDE _______________________________________

____

____

SLIDE MECHANISM ____

____

____

POSSIBLE/ACTION CONSEQUENCES OF SLIDE ____________________
(TRY TO ASSESS COST)

____

____

____

REMEDIAL ACTION TAKEN (TRY TO ASSESS COST) __________________

____

____

WHO WERE MAIN PEOPLE INVOLVED, HAS THERE BEEN A PAPER PUBLISHED ON THE ABOVE, IF SO WHERE? _____________________________

____

DID THE PIT SLOPE MANUAL CONTRIBUTE - CIRCLE WHERE APPLICABLE:

a. No contribution to above solution

b. 0-20% contribution

c. 20-40% contribution

d. 40-60% contribution

e. 60-80% contribution

f. 80-100% contribution

PIT SLOPE MANUAL

	Rating					Frequency of Use					General Comments
Chapter	Very Good	Good	Fair	Poor	Bad	High 80-100%	Mod. 50-80%	Fair 20-50%	Low 0-20%	None	- Updating - Revision - Usefulness
1. Summary											
2. Structural Geology											
3. Mechanical Properties											
4. Groundwater											
5. Design											
6. Mechanical Support											
7. Perimeter Blasting											
8. Monitoring											
9. Waste Embankments											
10. Environmental Planning											

CHECKLIST FOR GEOTECHNICAL CONSULTANTS

Date:

COMPANY: ______________________

Interviews (name, position):

- focus on 1972-1981 period.

INTRODUCTION

- were you directly involved with the CANMET pit slope project?
  - if so, on what aspects?
  - if not, why not?

- in general terms, what do you think the effect of the pit slope project and manual has been on open pit slope design and in civil construction:
  - in Canada?
  - internationally?

  with respect to:
  - improved information base and analysis
    - computer software?
    - CANMET vs 2nd generation?
  - improved design procedures?
  - improved support systems?
  - improved waste/tailings disposal?

- has the pit slope project, manual, and associated software affected the approaches to feasibility studies, design of pit slopes, etc. that you use in your consulting business?
  - if so, how?

MAJOR CHANGES IN PIT SLOPE DESIGN, PLANNING AND OPERATION

- how many rock slope problems has your organization dealt with, in Canada and internationally, during the 1972-82 period?

- main Canadian open pit mining and civil construction project you have been involved with

- in each case, what major changes has your work contributed to?

- dates of major changes

- classification of changes
  - improved information base and analysis
    - structural geology
    - mechanical properties
    - groundwater conditions
  - feasibility and design studies for new pits
  - improved slope design for existing pits
  - improved support systems
    - monitoring
    - perimeter blasting
    - mechnical support
  - improved waste and tailings embankments
  - other

- in each case:
  - how did the idea for change originate?
    - management
    - engineering staff
    - geotechnical staff
    - consultants
    - other
  - key people involved in analyzing effects of change; documentation in reports
  - alternatives considered; decision made
  - implementation of decision

- anticipated costs and benefits of change
  - costs
    - capital and operating
    - time distribution
  - benefits
    - slope angle changes: plus or minus
    - waste removed per year
    - stripping ratio
    - frequency of failure
    - cut-off grade and ore reserves
    - ultimate pit depth

- actual costs and benefits of change
  - classify as for 'anticipated costs and benefits' above

- were any of these changes related to:
  - CANMET pit slope project?
  - CANMET pit slope manual?

- if so, what specific aspects of the CANMET work were applied?

- if so, what explains the awareness of the CANMET work?
  - management/engineering staff
  - case study for project
  - manual
  - CANMET seminars
  - consultants
  - new graduates

- subjective estimate of percent range of actual costs and benefits which could be reasonably attributable to the pit slope project and manual

  e.g. 10-15 percent

  25-30 percent

PIT SLOPE MANUAL

- how often is it used; when did it start being used?

- is it being used more or less frequently with time?

- what parts have been used; for what purpose?

- what parts have not been used; why not?
  - too complex/sophisticated
  - irrelevant, etc.

- have the associated computer programs been used - when, for what, which ones, usefulness?

- is the manual in need of:
  - updating
  - revision
  - extension
  - simplification

  which parts?

- is the manual itself a useful way to transfer technology to open pit mining practice?
  - if not, why not?

- what other manuals/references of this type do you use?
  - how do they compare with CANMET manual?

- have you used the CANMET audio-visual packages on the manual?
  - if so, have they been useful?

- could the CANMET manual be usefully supported by seminars, training programs, etc.?

BUSINESS DEVELOPMENT

- growth of your organization's professional staff, in Canada and internationally, during 1972-1981 period

- growth of your business through 1972-1981 period in terms of billings:
  - Canada
  - foreign

- growth of billings made out of Canada coming back to Canada (i.e. export earnings)

- in each case, subjective estimates of percent which might be reasonably attributable to your involvement with the CANMET pit slope project

APPENDIX II

CRS STUDY QUESTIONNAIRES

EVALUATION OF THE CANMET PIT SLOPE PROJECT

QUESTIONNAIRE

OPEN PIT MINE DEVELOPERS AND OPERATORS

We are documenting improvements in stability associated with open pit mining which may have resulted from a better information base, more comprehensive feasibility and design studies for new mines, changes in slope design practices for existing operations, new support systems, and changes in waste and tailings embankment design and construction procedures.

1. With respect to the mine developments and operations you are responsible for, what significant changes in pit slope design, planning, and stability have occurred during the 1972-81 period?

2. In each case, why and how did the idea for the change originate? What was the result of the change in terms of the economics of the mine development or operation?

3. In each case, was the change which took place in any way attributable to the CANMET pit slope project or manual? If so, could we discuss these cases further with you?

4. When and how did you become aware of the CANMET pit slope manual? What parts of the manual do you use and for what purposes? Is the manual used more or less frequently with time? What parts of the manual have not been used? Why not? Which parts of the manual are in need of updating, revision, extension, or simplification? How does the CANMET manual compare with other manuals or references of this type that you use? Is the manual a useful way to transfer technology to open pit mining practice? How could the transfer of technology be improved?

EVALUATION OF THE CANMET PIT SLOPE PROJECT

QUESTIONNAIRE

GEOTECHNICAL CONSULTANTS

1. How has your consulting business developed during the 1972-81 period, e.g. in terms of professional staff employed in Canada and internationally? (It would be helpful if you could provide a profile of your company.)

2. In general terms, what do you think the effect of the CANMET pit slope project and manual has been on open pit slope design and civil engineering construction?

3. Was your company directly involved with the CANMET pit slope project? If so, in what respect? If not, why not?

4. Are the concepts, procedures and analysis techniques which you apply in your consulting business in any way attributable to the pit slope project or manual? If so, could we discuss this relationship further with you?

5. When and how did you become aware of the CANMET pit slope manual? What parts of the manual do you use and for what purposes? Is the manual used more or less frequently with time? What parts of the manual have not been used? Why not? Which parts of the manual are in need of updating, revision, extension, or simplification? How does the CANMET manual compare with other manuals or references of this type that you use? Is the manual a useful way to transfer technology to open pit mining practice? How could the transfer of technology be improved?

EVALUATION OF THE CANMET PIT SLOPE PROJECT

QUESTIONNAIRE

UNIVERSITY DEPARTMENTS

1. Were you directly involved with the CANMET pit slope project? If so, in what respect?

2. In general terms, what do you think the effect of the CANMET pit slope project and manual has been on open pit slope design and civil engineering construction?

3. Are the concepts, procedures and analysis techniques which you apply in your own research and consulting activities in any way attributable to the pit slope project or manual? If so, could we discuss this relationship further with you?

4. Is the CANMET pit slope manual used as a teaching aid, required text, or reference for courses given by your Department? If so, please provide brief outlines of the courses involved and in each case specify when the manual was first used, which parts are used, and in what way? Approximately how many students (by discipline) have taken each course involved since the manual was introduced?

5. When and how did you become aware of the CANMET pit slope manual? Which parts of the manual are in need of updating, revision, extension, or simplification? How does the CANMET manual compare with other manuals or references of this type that you use? Is the manual a useful way to transfer technology to rock slope design and open pit mining practice? How could the transfer of technology be improved?

EVALUATION OF THE CANMET PIT SLOPE PROJECT

QUESTIONNAIRE

MINE INSPECTORATES

1. Within your jurisdiction, what major changes in open pit slope design, planning, and practice have occurred during the 1972-81 period?

2. When and how did you become aware of the CANMET pit slope manual? What parts of the manual do you use and for what purposes? Is the manual used more or less frequently with time? What parts of the manual have not been used? Why not? Which parts of the manual are in need of updating, revision, extension, or simplification? How does the CANMET manual compare with other manuals or references of this type that you use? Is the manual a useful way to transfer technology to the design of rock slopes and open pit mining practice? How could the transfer of technology be improved?

3. What changes in open pit mine safety legislation and administration relating to slope design and stability have taken place in your jurisdiction during the 1972-81 period? Were these changes in any way attributable to the CANMET pit slope project or manual? If so, could we discuss these cases further with you?

4. Do you know of cases where the significance of actual or potential pit slides in terms of delay and disruption of open pit mining operations have been affected by application of the CANMET pit slope manual? If so, could we discuss these cases further with you?

EVALUATION OF THE CANMET PIT SLOPE PROJECT

QUESTIONNAIRE

OPEN PIT SUPPLIERS

1. How have the changes in open pit slope design and control which have taken place in Canada and internationally during the 1972-81 period affected the demand for your products and services? (It would be helpful if you could provide a profile of your company.)

2. When and how did you become aware of the CANMET pit slope manual? Which parts of the manual are in need of updating, revision, extension, or simplification? Is the manual a useful way to transfer technology to open pit mining practice? How could the transfer of technology be improved?

3. In general terms, what do you think the effect of the CANMET pit slope project and manual has been on open pit slope design and civil engineering construction?

4. Has the application of technology presented in the CANMET pit slope manual affected the development of your business? If so, in what ways? Could we discuss these cases further with you?

EVALUATION OF THE CANMET PIT SLOPE PROJECT

QUESTIONNAIRE

CIVIL ENGINEERING CONSTRUCTION

While the main focus of the CANMET pit slope project and manual is open pit mining, we are also attempting to document applications in civil engineering construction.

1. What significant changes in rock slope design and control have taken place in your organization during the 1972-81 period?

2. In general, do you think that the CANMET pit slope project and manual has had any effect on rock slope design and control in civil engineering construction? If so, in what ways?

3. Are the design and control procedures which your organization applies in any way attributable to the CANMET pit slope project or manual? If so, could we discuss these cases further with you?

4. When and how did you become aware of the CANMET pit slope manual? What parts of the manual do you use and for what purposes? Is the manual used more or less frequently with time? What parts of the manual have not been used? Why not? Which parts of the manual are in need of updating, revision, extension, or simplification? How does the CANMET manual compare with other manuals or references of this type that you use? Is the manual a useful way to transfer technology to rock slope design and control? How could the transfer of technology be improved?

APPENDIX III

MINE VISITS AND INTERVIEWS CONDUCTED

MINE VISITS

Endako: Placer Development
Date: June 1, 1982
Interviews: P. Harris (Peter), Chief Engineer
G. Grahams (Gordon), Senior Mine Engineer
P. Buckley (Paul), Senior Mine Geologist

Equity: Placer Development
Date: June 2, 1982
Interviews: J. Syr (James), Mine Geologist
J. Miller (Jack), Mine Engineer

Bell: Noranda Mines
Date: June 3, 1982
Interviews: R. Hamaguchi (Robert), Chief Engineer
R. McArthur (Ross), Pit Engineer

Granisle: Noranda Mines
Date: June 3, 1982
Interview: P. Kennedy (Patrick), Senior Engineer

Highmont: Teck Corporation
Date: June 4, 1982
Interviews: K. Bradley (Ken), Chief Engineer
L. Tsang (Louis), Geotechnical Engineer

Lornex: Lornex Mining Corporation
Date: June 7, 1982
Interviews: K. Munroe (Ken), Chief Engineer

Bethlehem: Bethlehem Copper (Cominco)
Date: June 8, 1982
Interviews: A. Bellamy (Allan), Chief Engineer
L. Stout (Lorence), Mine Planning Engineer

Brenda: Noranda Mines
Date: June 9, 1982
Interviews: G. Blackwell (Garston), Chief Engineer
P. Norish (Paul), Senior Mine Engineer
J. Keyes (John), Pit Superintendent

Afton: Teck Corporation
Date: June 10, 1982
Interviews: D. Stewart (Douglas), Chief Engineer
J. Rokosh (Joe), Special Projects Engineer

Similkameen: Newmont Mines
Date: June 11, 1982
Interview: J. McCue (James), Chief Engineer

Pipe: Inco (Manitoba Division)
Date: July 12, 1982
Interviews: G. Marshall (Gerald), Assistant Vice President, Mining
D. Browne (David), Chief Mine Engineer
R. Pero (Raymond), Manager, Open Pit and Outside Mines
K. Cassidy (Kevin), Mine Planning Engineer
K. Lowe (Ken), Mine Engineering Research
D. Sarin (David), Mine Engineering Research
P. Leinburger (Peter), Mine Engineer

Algoma: Algoma Steel
Date: July 13, 1982
Interview: R. Eldridge, Mine Superintendent

Kidd Creek: Kidd Creek Mines
Date: July 14, 1982
Interview: T. Yu (Thiann), Chief Engineer, Rock Mechanics

Sherman: Cliffs of Canada
Date: July 14, 1982
Interviews: S. Bardell (Sydney), Mine Manager
R. Garath (Robert), Mine Engineer, Environmental

Mount Wright: Quebec Cartier Mining
Date: July 15, 1982
Interviews: R. Bowman (Richard), Head, Technical Division
Y. Beauchamp (Yves), Mine Planner

Wabush: Wabush Mines
Date: July 16, 1982
Interviews: R. Foster (Robert), Mine Manager
R. Cannel (Royce), Chief Engineer
T. Matt (Terry), Pit Superintendent

Carol Lake: Iron Ore Company of Canada
Date: July 16, 1982
Interview: J. Smith (Joe), Senior Geologist

Brunswick 6: Brunswick Mining and Smelting
Date: August 9, 1982
Interviews: H. Debuck (Herman), Superintendent of Mines
P.J. Hurley (Philip), Mining Engineer
E. Brooks (Ernest), Geologist

Copper Mountain: Gaspe Mines Division, Noranda Mines
Date: August 10, 1982
Interview: G. Sauriol (Gilbert), Chief Engineer

King Beaver
British Canadian: Asbestos Corporation
Date: August 11, 1982
Interviews: A.H. Underwood (Arthur), Chief Engineer
A. Dufour (André), Mine Planning Engineer

Black Lake: Lac d'Amiante du Quebec
Date: August 11, 1982
Interviews: M. Lauzon (Maurice), Superintendent of Engineering
L. Bienvenu (Louis), Geotechnical Engineer

Jeffrey: Johns-Manville Canada
Date: August 12, 1982
Interviews: G.B. Coulombe (Bernard), Mine Manager
C.H. Lemay (Claude), Chief Engineer
J. Millin (John), Chief Geologist
B. Neville (Brian), Geotechnical Engineer

Syncrude: Syncrude Canada
Date: August 30, 1982
Interviews: G. Handford (Gerald), Soils Engineer
G. Kampala (Gray), Groundwater Engineer

OTHER INTERVIEWS CONDUCTED

Mine Operators and Developers

Island Copper: Utah Mines
Date: May 26, 1982
Interviews: T. Fright (Terry), Geotechnical Engineer
K. Pickering (Ken), Manager, Mine Technical Services

Schefferville: Iron Ore Company of Canada
Dates: June 28, September 24 and 29, 1982
Interview: O. Garg (Om), Director of Mine Planning, Hanna Mining (formerly Superintendent of Engineering, Knob Lake Division, Iron Ore Company of Canada)

Similkameen: Newmont Mines
Date: June 29, 1982
Interview: L. Kornzie (Larry), (formerly Geotechnical Engineer, Similkameen Division, Newmont Mines)

: Esso Resources Canada
Date: June 30, 1982
Interview: J.B. Evans (Blue), Director of Research (potential open pit mine developments)

: Manalta Coal
Date: July 5, 1982
Interviews: P. Scott (Paul), Manager of Engineering
G. Jenkins (Geoffery), Geotechnical Engineer
Q. Cobb (Quentin), Geotechnical Engineer
(Highvale, Whitewood, Roselyn, Vesta, Klimax, and Utility Mines)

Smokey River: McIntyre Mines
Date: July 8, 1982
Interview: G. Smith (Grant), Senior Staff Engineer (formerly Geologist, Clinton Mine, Cassiar Resources)

Line Creek: Crows Nest Resources (Shell)
Date: July 9, 1982
Interview: M. Robson (Michael), Supervising Engineer

Steep Rock: Steep Rock Iron Mines
Date: July 20, 1982
Interview: T. Wood (Tim), Manager, Resource Development

Elkford: Fording Coal
Date: August 10, 1982
Interview: B. Reipas (Beth), Geotechnical Engineer

Griffith: Pickands Mather
Date: August 24, 1982
Interviews: S. Schelske (Scott), Chief Engineer
F. Facca (Foster), Mine Geologist

Valley Copper: Valley Copper Mines
Date: August 25, 1982
Interview: S. Hodgson (Stanley), Senior Mining Engineer

Adams: Cliffs of Canada
Date: August 26, 1982
Interview: J.N. Tuomi (Jack), Mine Superintendent

Cassiar: Brinco
Date: August 26, 1982
Interview: C. Pulsifer (Cecil), Chief Engineer

Pine Point: Pine Point Mines
Date: September 3, 1982
Interview: W.R. Hargrave (William), General Manager

Gibraltar: Gibraltar Mines
Date: September 10, 1982
Interview: P. Nielens (Peter), Mine Engineer

Flin Flon: Hudson Bay Mining and Smelting
Date: September 30, 1982
Interview: D. Hanson (Doug), Senior Geotechnical Engineer, Research Engineer

Geotechnical Consultants

Steffen, Robertson and Kirsten
Date: May 19, 1982
Interview: A. Moss (Allan), Division Head

Golder and Associates
Date: May 21, 1982
Interviews: E. Hoek (Evert), Principal
P. Stacey (Peter), Division Head

Call and Nicholas
Date: May 21, 1982
Interview: R. Call (Richard), Principal

Thurbers
Date: May 26, 1982
Interviews: J. Gadsby (John), Principal
D.J. Poulter (David), Plant Ecologist

Brawner Engineering
Dates: May 31 and June 15, 1982
Interview: C.O. Brawner (Chuck), President

Piteau and Associates
Date: June 19, 1982
Interview: D. Piteau (Douglas), Principal

EBA Engineering
Date: July 5, 1982
Interview: A. MacRae (Allan), Manager, Industrial Group

Montreal Engineering Company
Date: July 5, 1982
Interview: R. Rennie (Ronald), Geotechnical Engineer

Techman Engineering
Date: July 7, 1982
Interviews: R. McCosh (Richard), Group Leader, Earth Sciences
D. LeBoeuf (Denis), Geotechnical Engineer (formerly with Knob Lake Division, Iron Ore Company of Canada)

Robertson, Dames and Moore
Date: August 17, 1982
Interview: K.E. Robinson (Keith), Principal

Dr. A. Bauer (Alan)
Date: September 27, 1982

Dr. P.N. Calder (Peter)
Dates: October 1 and 21, 1982

University Departments

Queen's University (Geological Sciences Department)
Date: April 28, 1982
Interview: D.F. Vandine (Douglas), Professor

University of British Columbia (Mineral Engineering Department)
Date: May 31, 1982
Interview: C.O. Brawner (Chuck), Professor

University of Alberta (Civil Engineering Department)
Date: July 5, 1982
Interview: D. Cruden (David), Professor

Laurentian University (Mining Engineering Department)
Date: July 19, 1982
Interview: V. Pakalnis Jr. (Victor), Adjunct Professor

University of Alberta (Mineral Engineering Department)
Date: August 16, 1982
Interview: B. Stimpson (Brian), Professor

Queen's Univeristy (Mining Engineering Department)
Dates: September 27 and October 1, 1982
Interviews: A. Bauer (Alan), Professor
P.N. Calder (Peter), Professor and Head

Mine Inspectorates

British Columbia Ministry of Energy, Mines and Petroleum Resources (Lower Mainland District, Chief Inspectorate)
Date: May 20, 1982
Interviews: W. Dudas (William), Inspector and Resident Engineer
W. Robinson (William), Chief Inspector

British Columbia Ministry of Energy, Mines and Petroleum Resources (Kamloops District)
Date: June 8, 1982
Interviews: J. McCulloch (James), Resident Engineer
D. Smith (David), Resident Engineer

Alberta Energy Resources Conservation Board
Date: July 6, 1982
Interviews: N. Duncan (Neil), Head, Coal Division
E. Mahadeo (Ernest), Senior Mining Engineer
D. Henderson (Donald), Senior Mining Engineer
B. Prasad (Brahn), Head, Mining Section, Oil Sands

Manitoba Department of Energy and Mines
Date: July 9, 1982
Interview: W. Bardswick (Bill), Director

Ontario Ministry of Labour (Mine Health and Safety)
Date: July 19, 1982
Interviews: V. Pakalnis Jr. (Victor), Chief Engineer
C. Graham (Charles), Senior Ground Control Engineer
P. McCrodan (Peter), Director

Quebec Ministry of Energy and Resources
Date: August 6, 1982
Interview: L.-G. Tanguay (Louis), Mining Engineer

Civil Engineering Construction

British Columbia Hydro
Date: June 25, 1982
Interviews: T. Little (Tim), Geotechnical Engineer
A. Imrie (Allen), Head of Geotechnical Department

British Columbia Rail
Date: September 30, 1982
Interview: J.C. Leighton (John), Rock Mechanics Engineer
(formerly with B.C. Department of Highways)

APPENDIX IV

CASE STUDY DOCUMENTATION

Case 1

In 1979, as a mining operation was approaching its ultimate pit walls, the pit was redesigned based on the compilation and analysis of structural geological information. The procedures used to compile the structural data were those specified in the CANMET Pit Slope Manual. The Discodat computer program from the manual was applied to analyze and interpret the structural geological information.

As a result of the redesign of the pit, a 1500 metre length of pit wall was steepened from 45 degrees to 50 degrees. The steepening of this wall enabled the mining of an additional 9.6 million tonne wedge of rock over a vertical distance of about 170 metres, consisting of 6.5 million tonnes of ore and 3.1 million tonnes of waste rock. This wedge will be mined from 1985 to 1994.

If the pit had not been redesigned in 1979, it is probable that it would have been at some future date, estimated as follows:

lower limit	1981;
most-likely value	1984;
upper limit	1987.

It is assumed that the pit wall would have been steepened from 45 degrees to 50 degrees from this point in time on, permitting mining of the then recoverable part of the total wedge.

Estimated share of the benefit associated with the actual case study attributable to the the Pit Slope Manual:

lower limit	20%;
most-likely value	30%;
upper limit	40%.

The simulated present values of benefits attributable to the CANMET pit slope project for this case study are summarized as follows ($ thousand):

lower limit	1,418;
most-likely value	2,211;
expected value	2,295;
upper limit	3,242.

Cases 2-3

Control blasting procedures were introduced on an ad hoc basis at an open pit mine from the late sixties and had realized substantial savings resulting from increased slope angles and reduced stripping by the mid-seventies. At that time, the mine was acquired by a company with existing mining operations in the province. The organizational structure of the two mining centres was integrated at a senior level.

Case 2

From the mid-seventies, control blasting procedures were implemented at the other mining centre. The pre-shear blasting system introduced enabled mining to be carried out using triple benches, with a bench face angle of 80 degrees. Due to the improved wall control which resulted, the overall slope angle at the largest of three open pits was steepened from the original design of 50 degrees to 60 degrees. This increase in slope angle was applied to two pit walls, each having a length of 3500 metres and an affected height of 90 metres, reducing waste excavation requirements by a projected 20 million tonnes during the period 1980-2003.

While the impetus for this improvement came from the successful previous experience, the general design approach for perimeter blasting developed as part of the CANMET pit slope project made an important contribution to its implementation in 1980. Otherwise, it is estimated that the change would only have been introduced as follows:

lower limit	1982;
most-likely value	1983;
upper limit	1984.

Estimated share of the benefit associated with the actual case study change attributable to the CANMET pit slope project:

lower limit	15%;
most-likely value	20%;
upper limit	25%.

The simulated present values of benefits attributable to the CANMET pit slope project for this case study are summarized as follows ($ thousand):

lower limit	446;
most-likely value	704;
expected value	699;
upper limit	1,004.

Case 3

Within this more general advance in applied technology, a specific improvement in control blasting practice was also achieved at this operation. The pre-split line for perimeter blasting utilizes 3-inch percussion holes drilled at an 80 degree angle. Existing industry practice would have established a 4 foot spacing between holes. Application of the design approach recommended in the perimeter blasting chapter of the CANMET Pit Slope Manual enabled an 8 foot hole spacing to be achieved by 1982, resulting in a significant reduction in control blasting costs.

If this change had not been initiated in 1982, it is probable that a similar improvement would have been made in the future, estimated as follows:

lower limit	1984;
most-likely value	1987;
upper limit	1990.

Estimated share of the benefit associated with the actual case study change attributable to the Pit Slope Manual:

lower limit	20%;
most-likely value	25%;
upper limit	30%.

The simulated present values of benefits attributable to the CANMET pit slope project for this case study are summarized as follows ($ thousand):

lower limit	64;
most-likely value	159;
expected value	156;
upper limit	248.

Case 4

During the late seventies, the CANMET Pit Slope Manual was used at an open pit mine to help create a general awareness of rock stability parameters, and to develop confidence in the monitoring, prediction, and control of slope failures.

In 1979, as the mine was approaching the end of its productive life, a major potential area of instability in one pit wall threatened the recovery of 6.4 million tonnes of ore scheduled for extraction in 1980 and 1981. The general understanding of pit slope engineering which had been built up at the mine, combined with the use of an electronic distance measuring monitoring system, provided mine management with the confidence and control necessary to extract the ore block under safe working conditions. Otherwise, the endangered area of the mining operation would have had to have been shut down and the 6.4 million tonne block of ore left in place, with no practical possibility of future access or recovery.

Estimated share of case study benefit attributable to the Pit Slope Manual:

lower limit	5%;
most-likely value	10%;
upper limit	15%.

The simulated present values of benefits attributable to the CANMET pit slope project for this case study are summarized as follows ($ thousand):

lower limit	1,069;
most-likely value	2,129;
expected value	2,153;
upper limit	3,266.

Case 5

The blasting practice applied in the mid-seventies at an open pit mine resulted in sloughing and deterioration of the pit walls and required an extensive program of mechanical support to maintain acceptable mining conditions. During the 1976-78 period, a major testing program was carried out to develop improved blasting procedures. The design approach applied was based in part on the perimeter blasting chapter of the CANMET Pit Slope Manual.

The new control blasting system, successfully introduced in 1978, utilized the CANMET manual to obtain smooth pit walls, which previously contained a substantial amount of backbreak and slough. This improved condition was due to the new practice of pre-shearing the final wall. These drill holes were spaced 7 feet apart and decoupled to 1 3/4 inch diameter. Previously, minimal wall control blasting was employed. While the same overall slope angle was maintained, the primary benefit of the change was being able to operate in a much safer pit.

A secondary benefit associated with the change, the focus of this case, was that the mechanical support program was no longer required. This saving applied over a 650 metre length of pit wall, from the then existing mining depth of 100 metres to the projected ultimate pit depth of 350 metres, over a remaining 30 year mine life.

If the improved blasting practice had not been implemented in 1978, it is probable that a similar change would have been made at some future time estimated as follows:

lower limit	1980;
most-likely value	1983;
upper limit	1986.

Estimated share of the benefit associated with the actual case study change attributable to the CANMET Pit Slope Manual:

lower limit	15%;
most-likely value	20%;
upper limit	25%.

The simulated present values of benefits attributable to the CANMET pit slope project for this case study are summarized as follows ($ thousand):

lower limit	40;
most-likely value	76;
expected value	76;
upper limit	116.

Case 6

An open pit mine was originally designed on the basis of a minimum acceptable berm width of 8 metres, and an overall pit slope angle of 45 degrees. The blasting procedures employed in the late seventies did not allow the minimum 25 foot berm width to be maintained. This was due to the 10 foot overbreak which resulted from their blasting practice. In order to maintain the minimum berm width it would have been necessary to flatten the overall pit slope angle from 45 degrees to 39 degrees. The alternative was to reduce backbreak which was the approach followed. This was made possible by the application of control blasting.

The CANMET Pit Slope Manual was instrumental in increasing the awareness of mine management and engineering staff to the potential for improvement. In 1980, the guidelines provided in the perimeter blasting chapter of the manual were specifically followed in designing and implementing a control blasting system. This new blasting practice enabled the 45 degree overall slope angle to be maintained employing the original design specifications.

The new control blasting system resulted in a projected reduction of 62.6 million tonnes of waste excavation which it would have been necessary to remove if the pit slope angle had been reduced to 39 degrees. This waste stripping would otherwise have occurred during the period 1980-91, requiring an increase in waste handling capacity to maintain ore throughput.

If this improved blasting practice had not been initiated in 1980, the pit walls would have been flattened. However, it is probable that a similar improvement would have been introduced at a later date, estimated as follows:

lower limit	1982;
most-likely value	1984;
upper limit	1986.

It would have been possible to steepen the pit walls to 45 degrees from this point on, resulting in the saving of a corresponding part of the 62.6 million tonne waste stripping requirement.

Estimated share of the benefit associated with the actual case study change attributable to the Pit Slope Manual:

lower limit	40%;
most-likely value	50%;
upper limit	60%.

The simulated present values of benefits attributable to the CANMET pit slope project for this case study are summarized as follows ($ thousand):

lower limit	8, 978;
most-likely value	12, 350;
expected value	11, 897;
upper limit	15, 453.

Case 7

Berms along the hanging wall of an open pit mine had progressively deteriorated to the point where, by late 1974, an extensive failure was possible. The disturbed rock structure endangered the safety of men and equipment travelling along the main haulage ramp, the only access to the pit bottom. Consequently, mine management decided to adopt a mechanical support and monitoring program to hopefully provide the necessary protection.

The support and monitoring program was implemented and completed in 1975 under contract as part of the CANMET pit slope project. Government participation represented about 19 percent of the total cost of $413,000. The program consisted of scaling, screening, and cable bolting over a 150 metre long by 40 metre high area of pit wall, and the installation of a monitoring system. The program proved successful in controlling and stabilizing the affected area.

The next best alternative to the program adopted was to attempt to remove the unstable part of the pit wall by drilling and blasting. Because of the badly disturbed nature of the existing rock structure, the direct cost and time involved in achieving an acceptable solution by this means were highly uncertain. The main haulage ramp would have had to have been closed and mine production suspended for an uncertain period, estimated as follows:

lower limit	2 weeks;
most-likely value	2 months;
upper limit	6 months.

Estimated share of case study benefit attributable to CANMET pit slope project:

lower limit	15%;
most-likely value	20%;
upper limit	25%.

The simulated present values of benefits attributable to the CANMET pit slope project for this case study are summarized as follows ($ thousand):

lower limit	138;
most-likely value	535;
expected value	732;
upper limit	1,580.

Cases 8 and 9

During the period 1973-74, a slope stability study was undertaken at an open pit operation including rock strength measurement, compilation of structural geological data, surveying of groundwater conditions, and the installation of a monitoring system. The project was mainly carried out under contract as part of the CANMET pit slope project. Government funding provided 63 percent of the $447,000 total contract cost.

Based on results of the slope stability study, the open pit was redesigned in 1975, and the design changes were implemented in 1976. CANMET personnel provided advice during the redesign and made a particularly important contribution in encouraging the application of probability of failure analysis.

The share of benefits associated with the two actual case study changes described below attributable to the CANMET pit slope project is estimated as follows:

lower limit	10%;
most-likely value	15%;
upper limit	20%.

Case 8

Resulting from the redesign of the open pit, inter-ramp angles for three of the pit walls were steepened from 45 degrees to 53 degrees and, consequently, overall slope angles were increased from 37.5 degrees to 43.5 degrees. As a result, waste stripping requirements have been reduced by a projected 113.4 million tonnes during the 1982-90 period.

If this design change had not been made in 1976, it is probable that a similar improvement would have been implemented at some future time, estimated as follows:

lower limit	1978;
most-likely value	1981;
upper limit	1984.

The simulated present values of benefits attributable to the CANMET pit slope project for this case study are summarized as follows ($ thousand):

lower limit	2,624;
most-likely value	5,107;
expected value	5,347;
upper limit	9,019.

Case 9

Prior to implementation of the new design, the pit was operating with 40 metre wide safety catchment berms and 80 metre high benches. The slope stability study gave mine management sufficient confidence to reduce the safety berms to 20 metres and to only bench to a 40 metre height.

Applying this procedure, the mine was able to reduce the amount of waste excavated in 1975 by 11 million tonnes. Since this saving was virtually immediate, if these changes had not been made at that time, it would have been necessary to remove the additional waste.

The simulated present values of benefits attributable to the CANMET pit slope project for this case study are summarized as follows ($ thousand):

lower limit	1,098;
most-likely value	1,660;
expected value	1,650;
upper limit	2,172.

Case 10

In 1982, a provincial government department had to establish guidelines for the administration of regulations which required tailings impoundment structures to be 'designed in accordance with good engineering practice'. The waste embankments chapter of the CANMET Pit Slope Manual was used for this purpose.

The alternative to using this chapter would have been for the department to develop its own tailings impoundment manual at a cost estimated as follows:

lower limit	$20,000;
most-likely value	$35,000;
upper limit	$50,000.

In this case, the total benefit is attributable to the Pit Slope Manual.

Case 11

The CANMET Pit Slope Manual provided the chief engineer at an open pit mining operation with his first exposure to rock mechanics principles and, in so doing, helped him develop a general awareness of pit slope stability and mechanisms for controlling rock failure.

In 1981, a haul road located 60 metres below a potential slide was in danger of being blocked. This road was the sole access to the pit bottom which at that time was 200 metres below surface. The slide zone consisted of a hard dacite lacolith resting on tertiary sediments which were bentonitic in nature. The potential failure encompassed an area approximately 160 metres in lateral extent and 70 metres high. The stabilization procedure adopted by the chief engineer was suggested by knowledge gained from the CANMET manual. The solution was to mine 80,000 tonnes of waste rock from the potential slide area. This resulted in flattening the wall angle from 45 degrees to 30 degrees in the vicinity of the potential failure.

The alternative to relieving the instability in this way would have been to step out from the existing pit wall and leave a safety berm. In this case, the main pit haulage road would have required relocation, causing a two week loss of mine production. Also, the safety berm would have resulted in losing access to 175,000 tonnes of ore scheduled for mining in 1986.

Estimated share of case study benefit attributable to the Pit Slope Manual:

lower limit	5%;
most-likely value	10%;
upper limit	15%.

The simulated present values of benefits attributable to the CANMET pit slope project for this case study are summarized as follows ($ thousand):

lower limit	140;
most-likely value	265;
expected value	268;
upper limit	394.

Case 12

Engineering personnel at an open pit mining operation participated in the CANMET pit slope project in the areas of pit dewatering, structural geological mapping, and shear testing. This experience, as well as more general exposure to the Pit Slope Manual, gave both engineering staff and mine management an increased awareness of the parameters affecting rock slope stability and control.

As a result of this increased awareness, a decision was taken to implement a new monitoring program at the mine. The monitoring chapter of the manual provided guidance for the selection of a particular electronic distance measuring system. This system was installed in 1977.

Shortly after installation, the monitoring program successfully predicted a 5,000 tonne rock slide on a bench which was approaching the ultimate pit limit. If the new monitoring system had not been in place, a safety berm would have had to be incorporated in the vicinity of the potential slide and carried to the ultimate pit bottom in order to ensure the safety of workings below the toe of the potential slide. This would have affected an area 200 metres in lateral extent and 200 metres in depth. A 30 metre width would have been required for this catchment berm. The associated 2.7 million tonne block of rock consisted of one-third ore and two-thirds waste material. The monitoring system enabled production holes to be safely drilled in the endangered bench at the top of this block, and consequently, these 2.7 million tonnes will be available for mining, starting in 1992 and lasting for nine years (to the year 2000). Otherwise, drilling access to the bench would have been lost and recovery of the block would not have been feasible.

Estimated share of case study benefit attributable to CANMET pit slope project and manual:

lower limit	15%;
most-likely value	25%;
upper limit	35%.

The simulated present values of benefits attributable to the CANMET pit slope project for this case study are summarized as follows ($ thousand):

lower limit	215;
most-likely value	351;
expected value	353;
upper limit	486.

Cases 13-17

In 1970, the engineering department responsible for a complex of open pit mines made a small start on their own initiative in assembling basic technical data concerning the associated deposits. This effort then had to be suspended for a year. In 1971, engineering staff provided the first economic justification for continuing work on the technical data base in terms of potential savings in waste stripping and improved pit scheduling. This received a favourable response from management and the collection of information was reinstituted. Much useful data began to be assembled concerning structural geological features, groundwater conditions, rock strengths, and permafrost conditions.

In-house collection and analysis of data continued into 1972. Also, three university studies on topics of concern for the program were commissioned. At mid-year, initial discussions were held with CANMET concerning this program. In so doing, the company was seeking outside advice about whether it was on the right track in working towards technical improvements in the efficiency of its mining operations. At the same time, it was looking for practical results of CANMET research which could be applied. At this time, CANMET and the company agreed to cooperate on technological concerns of mutual interest. These initial discussions were important in reinforcing the confidence of the engineering group in its study program.

When the CANMET pit slope project was initiated later in 1972, corporate restrictions did not allow the company to participate directly as a contractor. However, all the fieldwork data assembled was provided at company cost. This then formed the basis for analysis by CANMET staff as part of the pit slope project. Also, particular components of the data base were assigned for analysis to two consulting groups under contract to CANMET also as part of the pit slope project.

This work continued through 1973 with initial results being provided by CANMET, the two consultants, and the three universities. At the same time, in-house studies continued with emphasis shifting to the integration and application of results. By mid-1974, preliminary recommendations were made by the engineering department for change in the mining operations, particularly with regard to the steepening of pit slope angles.

In late 1975, following a critical and lengthy process of communication, education, and discussion, management gave tentative approval for redesign of five of the existing open pit mines. Then, in early 1976, management took the decision to implement steeper pit slope angles in practice, as outlined below for the five case studies.

Case	Overall Pit Slope Angle (degrees)		Reduction in Waste Excavation (million tonnes)	Time Period
	Before Change	After Change		
Case 13	37.5-45	42.5-50	5.5	1976-83
Case 14	45	55-62	15.75	1976-78
Case 15	42.5-45	50	5.8	1976-79
Case 16	37.5-45	50-55	5.0	1976-79
Case 17	42.5-45	50-55	11.25	1976-84

If these changes in pit slope design had not been introduced in 1976, it is possible that similar improvements would have been made at some future time. However, these cases illustrate the long lead time and improbable combination of circumstances required to successfully implement technological change. The following estimates are made of dates when such changes might otherwise have occurred:

lower limit	1978;
most-likely value	1981;
upper limit	1984.

The share of benefits associated with the five actual case study changes attributable to the CANMET pit slope project is estimated as follows:

lower limit	20%;
most-likely value	25%;
upper limit	30%.

The simulated present values of benefits attributable to the CANMET pit slope project for these five case studies are summarized below ($ thousand):

Case	Lower Limit	Most-Likely Value	Expected Value	Upper Limit
Case 13	438	1,084	1,080	1,681
Case 14	4,019	6,694	6,268	7,971
Case 15	1,045	2,129	1,846	2,543
Case 16	868	1,795	1,552	2,144
Case 17	452	1,645	1,603	2,948

Case 18

In 1973-74, CANMET personnel responsible for the pit slope project provided advice to an open pit mining operation regarding potential for improvement and were instrumental in initiating a slope stability study at the mine.

This study, carried out in 1974-75, included the compilation of structural geological information, rock strength measurement, and the testing of control blasting procedures. As a result, starting in 1976, the overall pit wall angle was steepened from 45 degrees to 50 degrees, resulting in a reduction of 4.6 million tonnes of waste stripping prior to mine closure in 1978.

If this design change had not been implemented in 1976, it is probable that a similar improvement would have been made at some future date estimated as follows:

lower limit	1978;
most-likely value	1980;
upper limit	1982.

However, it is unlikely that the change could otherwise have been made to benefit the mine before it closed.

Estimated share of the benefit associated with the actual case study change attributable to the CANMET pit slope project:

lower limit	30%;
most-likely value	40%;
upper limit	50%.

The simulated present values of benefits attributable to the CANMET pit slope project for this case study are summarized as follows ($ thousand):

lower limit	396;
most-likely value	746;
expected value	682;
upper limit	931.

Case 19

The perimeter blasting chapter of the CANMET Pit Slope Manual were applied to help improve the efficiency of pillar recovery at an underground mine. The mining method used involves modified longhole open stoping.

Blasting vibration studies carried out at the mine in 1980-81 have been applied to modify blasting procedures for the recovery of four pillar blocks, each of approximately 350,000 tonnes, which are being mined in sequence over the 1982-85 period. Consequently, drill holes were loaded with the objective of reducing vibration and minimizing tensile slabbing. The blasting design approach recommended in the CANMET manual, including the use of a peak particle velocity relationship, made an important contribution to implementing this change.

The new blasting procedure has resulted in a reduction in blasting damage and improved stability of the stope walls. Consequently, there has been a marked reduction in waste rock dilution, from 15 percent of ore reserves with previous blasting practice to an estimated 5 percent.

If this change had not been initiated in 1982, it is probable that a similar improvement would have been made at some future time estimated as follows:

lower limit	1984;
most-likely value	1986;
upper limit	1988.

However, it is unlikely that the change could otherwise have been made in time to benefit the extraction of the four pillar blocks.

Estimated share of the benefit associated with the actual case study change attributable to the Pit Slope Manual:

lower limit	20%;
most-likely value	25%;
upper limit	30%.

The simulated present values of benefits attributable to the CANMET pit slope project for this case study are summarized as follows ($ thousand):

lower limit	269;
most-likely value	463;
expected value	398;
upper limit	548.

Case 20

In the mid-seventies, all pit walls at a mining operation were designed at 45 degrees. Pit design optimization and slope stability studies were first considered in 1976, in part because of an awareness of potential for improvement resulting from participation of engineering staff from the mine at one of the CANMET seminars on the pit slope manual.

A major pit design study was completed in 1979, with recommendations for the second stage of pit development. The CANMET Pit Slope Manual was used extensively in this study, especially the design, monitoring, and blasting chapters, particular problem areas for the mine.

The study recommendations were not initially adopted. In 1982, when two-thirds of the pit wall area had developed slope failures, the study recommendations were finally implemented. The design changes arising from the study have now been extended for use in planning the third stage of pit development. One particular benefit of the new design is that it allows a 500 metre length of pit wall to be steepened from 45 degrees to 52 degrees for a depth of 230 metres. This will reduce waste stripping requirements by a projected 6.2 million tonnes during the 1984-87 period.

If the design change had not been initiated in 1982, it is probable that a similar improvement would have been made at some future date, estimated as follows:

lower limit	1984;
most-likely value	1987;
upper limit	1990.

Estimated share of the benefit associated with the actual case study change attributable to the Pit Slope Manual:

lower limit	15%;
most-likely value	20%;
upper limit	25%.

The simulated present values of benefits attributable to the CANMET pit slope project for this case study are summarized as follows ($ thousand):

lower limit	105;
most-likely value	478;
expected value	409;
upper limit	704.

APPENDIX V

POTENTIAL BENEFITS OF ADVANCES IN PIT SLOPE TECHNOLOGY IN THE CANADIAN NONFERROUS MINING SECTOR

In this appendix, the potential economic benefits associated with general advances in pit slope technology are assessed. For this purpose, we consider the effects of technological advances made during the past decade on the Canadian nonferrous mining sector.

As has been pointed out in chapter 3, nonferrous mining activity is the single most important component of open pit mining in Canada in terms of value of production. Assessment of potential benefits associated with advances made during the past decade provides useful perspective for the more specific case study results evaluated, and a rough check on the benefits which may be attributable to the CANMET pit slope project.

Data Base

The assessment of potential benefits is based on the deposit-specific data base and methodology which have been developed at the Centre for Resource Studies. For present purposes, the deposit base consists of 80 nonferrous metal deposits discovered in Canada during the 1946-77 period which are mineable, at least in part, by open pit methods. A listing of these deposits by province is given at the end of this appendix. The following breakdowns of mining characteristics should be noted.

i Sixty-one of the deposits are mineable entirely by open pit methods. The other 19 deposits are initially mined from an open pit, and then by underground methods.

ii Fifteen of the deposits were mined during the past decade but are now either depleted or have advanced to an underground mining phase. Twenty of the open pits are currently operating, representing over 95 percent of presently installed open pit capacity in the Canadian nonferrous sector. The remaining 45 deposits, currently undeveloped, are potentially available for future mine replacement and growth.

This deposit data base contains a realistic mixture of large-scale open pit porphyry mines, mainly in British Columbia, and smaller, higher-scale open pit situations typically located in the territories and in eastern Canada, which are often only partially mined from the surface. The inclusion of past, present, and possible future mining operations provides a full representation of nonferrous open pit characteristics.

These 80 deposits, it is suggested, provide the best possible base for making a composite long-term assessment of the potential benefits of advances in pit slope technology.

Methodology

For our assessment purposes, each of the deposits is evaluated under current economic and technological outlook conditions. Within this framework, the sensitivity of results to possible improvements in pit slope angles associated with advances made during the past decade is examined.

All money values are expressed in constant 1980 dollars. An 8-percent discount rate is used as our best estimate of the weighted average cost of capital, in constant money terms, typifying investment in the nonferrous mining sector.

Metal price is both the most important and the most uncertain variable in the evaluation of the 80 open pit deposits. Therefore, cash flows are evaluated as a function of price. For this purpose, a most-likely price outlook is bounded by 90 percent upper- and lower-limit prices for each metal. The prices used, shown in table 14, are long-term average price estimates, and thus due to the volatility of metal price cycles, are not directly related to the fifty-year-low prices currently prevailing.

Table 14
LONG-TERM PRICE VARIANTS FOR ANALYSIS
(1980 Dollars, U.S. Funds)

Metal	Price Basis	Lower Limit Prices	Most Likely Prices	Upper Limit Prices
Bismuth	Per pound metal	1.50	2.00	2.50
Cadmium	Per pound metal	2.00	2.50	3.00
Cobalt	Per pound metal	12	15	25
Copper	Per pound metal	.85	1.00	1.35
Gold	Per pound metal	500	600	900
Lead	Per pound metal	.32	.42	.62
Molybdenum	Per pound in concentrate	6.50	8.00	11.00
Nickel	Per pound metal	2.75	3.25	4.25
Palladium	Per pound metal	120	200	300
Platinum	Per pound metal	450	600	800
Silver	Per pound metal	13	17	25
Zinc	Per pound metal	.35	.40	.55
Exchange Rate	$US/$C	1.00	.85	.75

The assessment of costs and revenues assumes that nonferrous metal concentrates are produced at each of the open pit mines. General net smelter return conditions for copper, lead, nickel, and zinc concentrates are used to work the assumed metal prices back to a revenue estimate for the sale of concentrate.

Individual deposit estimates of recoverable ore reserves, ore capacity, preproduction period, preproduction capital cost, the cost of major modifications, sustaining capital, operating costs, metallurgical recoveries, concentrate grades, and concentrate transportation, are required for each of the 80 open pit deposits, based on present-day economic and technological conditions. These deposit estimates are based on actual historical data to the extent available. Otherwise, generalized costing relationships are applied, reflecting an order of magnitude level of accuracy.[45]

Each open pit mine is first evaluated on a potential value or before-tax basis. Then current federal corporate income tax, provincial corporate income tax, and provincial mining tax systems are applied to determine the effect of taxation on sharing before-tax cash flows between industry and government.

Potential and after-tax results for the 80 deposits are averaged to determine composite values per deposit, with and without the advances in pit slope technology which have been realized during the past decade. Differences between the 'with' and 'without' evaluations are then used to assess the potential benefits associated with the advances expressed as averages per deposit, and per tonne of ore mined, and, then, as a total for the nonferrous mining sector.

Advances in Pit Slope Technology

We now turn to consider the increase in pit slope angle which could potentially have resulted from technological advances achieved during the past decade, and the possible effects of this increase on improving open pit mining parameters.

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45. For further details concerning the data base and methodology see Economic Effects of Smelter Controls on the Canadian Nonferrous Mining Industry, B.W. Mackenzie and M.L. Bilodeau, technical paper no. 2, Centre for Resource Studies, January 1982, chapters 2 and 3.

Based on the broad spectrum of mine visits, interviews, and case study documentation carried out as part of this study, on actual data obtained, and on the informed opinions of geotechnical consultants, we estimate a most-likely average increase in overall pit slope angle of 5 degrees. This judgment obviously represents a highly uncertain subjective opinion. Consequently, we have bounded this estimate with 90 percent lower- and upper-limit values of 2 degrees and 10 degrees respectively. We are confident that the actual average improvement in pit slope angle resulting from the past decade's advances lies within these limits, and that it is likely to lie closer to the five degree most-likely estimate than to either of the limits.

This increase in average pit slope angle can be applied to improve the economics of open pit mining in one of two basic ways:

i reducing the amount of waste excavated and, hence, lowering the average stripping ratio.[46]

ii increasing the amount of recoverable ore reserves by lowering the ultimate pit bottom.

A simplified but generally realistic assumption has been made regarding deposit configuration and pit geometry to convert possible increases in overall pit slope angle to improvements in each of these open pit mining parameters. Results are presented in table 15.[47]

If the increase in pit slope angle is used to increase recoverable ore reserves, we further consider that this improvement can take one of two possible forms. First, the existing open pit mine capacity can be maintained, in which case the increase in ore reserves will have the benefit of lengthening mine life. Second, the increase in ore reserves can provide the basis for an expansion of mine capacity, raising the investment requirement, increasing annual cash flows, and more marginally lengthening mine life.

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[46] The average stripping ratio is the amount of waste excavated divided by the ore mined. Thus, an average stripping ratio of 2:1 means that two tonnes of waste are removed on average for each tonne of ore mined.

[47] We have assumed a vertical deposit of uniform width and a truncated-wedge shape for the open pit, similar to case A in figure 4. The resulting improvements are relatively modest compared with those associated with the assumption of wedge-shaped or, particularly, cone-shaped pit configurations. See 'Pit Slope Design', R. Sage, The Northern Miner, November 27, 1975.

Table 15

IMPROVEMENT IN OPEN PIT MINING PARAMETERS ASSOCIATED WITH STEEPER PIT SLOPE ANGLES

Average Improvement in Overall Pit Slope Angle	Reduction in Average Stripping Ratio[a]	Increase in Recoverable Ore Reserves
2 degrees	7 percent	7 percent
5 degrees	16 percent	19 percent
10 degrees	30 percent	43 percent

[a] For example, if an average stripping ratio of 2:1 is reduced by 16 percent, 1.68 tonnes of waste would be excavated from the pit on average for each tonne of ore recovered.

Table 16

AVERAGE BENEFIT OF ADVANCES IN PIT SLOPE TECHNOLOGY FOR A NONFERROUS OPEN PIT MINE: BASE CASE CONDITIONS

Alternative	Increase in Before-Tax Cash Flow ($ million)	Increase in NPV at Start of Development ($ million)
Reduction in waste excavation	22.5	9.9
Increase in ore reserves:		
fixed capacity	74.9	14.8
variable capacity	84.6	31.8

Table 17

AVERAGE BENEFIT OF ADVANCES IN PIT SLOPE TECHNOLOGY FOR A NONFERROUS OPEN PIT MINE: SLOPE ANGLE VARIANTS

		Increase in Ore Reserves	
	Reduction in Waste Excavation	Fixed Capacity	Variable Capacity
Increase in Before-Tax Cash Flow ($ million)			
2 degree improvement	8.4	32.0	37.8
5 degree improvement	22.5	74.9	84.6
10 degree improvement	51.2	137.2	157.7
Increase in NPV at start of development ($ million)			
2 degree improvement	3.7	5.7	14.3
5 degree improvement	9.9	14.8	31.8
10 degree improvement	22.1	28.8	60.2

To summarize, we are evaluating the possible economic effects associated with three possible alternatives for capturing the benefits resulting from steeper pit slope angles:

i reduction in waste excavation;
ii increase in ore reserves - fixed capacity;
iii increase in ore reserves - variable capacity.

In practice, mine management will likely endeavour to achieve some balance of benefits among these alternatives.

Presentation and Analysis of Results

We can now proceed to assess the potential benefits of advances in pit slope technology during the past decade with respect to the Canadian nonferrous mining industry.

The emphasis here is on potential value or before-tax results since our main interest is the overall benefit to society associated with technological advances. Only at the very end do we deal with taxation effects, and the apportioning of the before-tax social benefit to industry and government which results.

All results represent a composite average of the 80 actual open pit deposits evaluated. Initially, assessments are made of the average increase in before-tax cash flow, and the average increase in net present value at the start of development for an average or typical nonferrous open pit mine. Since each deposit is evaluated on the basis of current outlook conditions, as if we had it in hand today for possible development, the start of development should be thought of as the year 1982. This then is consistent with the evaluation procedure adopted in the case study analysis in chapter 5.

Potential value results are presented in table 16 for most-likely base case conditions - the 5 degree increase in pit slope angle and the most-likely set of metal prices. Under these circumstances, the average benefit associated with an open pit mine is substantial for all three of the alternatives considered. The average improvement in net present value varies from about $10 million to $32 million, being lowest when the improved slope angle is used to reduce waste removal, and highest when it is applied to increase ore reserves and expand capacity, assuming that there are in fact deeper ore reserves.

Table 17 shows, as would be expected, that potential benefits are highly sensitive to the improvement in pit slope angle considered. The results shown assume most-likely metal price conditions. As this improvement is varied through the 2 degree to 10 degree confidence interval, net present values increase by four to six times, the increase being most pronounced when the steepened slope angle is used to reduce waste excavation. The average enhancement in net present value varies from about $4 million to $60 million per deposit. The relative dollar-value positions of the three alternatives remain unchanged.

Results illustrating the sensitivity of potential benefits to metal prices are presented in table 18, assuming the 5 degree improvement in slope angle. Reduced waste removal only affects mining costs so these benefits are independent of metal prices. However, the potential benefits of the increased ore reserve alternatives have both revenue and cost components and, thus, are sensitive to prevailing metal prices. As metal prices are increased through the lower- to upper-limit price interval, the net present value of these alternatives is increased between six to almost nine times. The variable capacity alternative always yields greater benefits than when capacity is assumed fixed. At lower limit prices, a reduction in waste stripping is more attractive than either of these alternatives. The average improvement in net present value varies from about $5 million to $69 million per open pit mine.

In order to reduce the wide range of possible benefits shown in tables 16-18 to more manageable proportions, from here on a balance among the three alternatives is considered. A reduction in waste excavation, although in general yielding the lowest potential benefit, is the payoff which is most immediate, lowest risk, easiest to quantify, and most commonly encountered. The benefits associated with the increased ore reserve alternatives, while generally characterized by high payoffs, are influenced by a much wider range of uncertain variables including ore grades and metal prices. With mine capacity fixed, potential benefits are only realized towards the end of mine life. The variable capacity alternative, while realizing the highest payoff in general, requires investment in incremental capacity and may not in fact be feasible in some cases due to financing or marketing constraints. Given these factors, there is clearly not one best alternative. From here on, we assume that one-third of the potential benefit will typically be realized from each of the three alternatives.

Now, how can we apply our findings to assess the potential total benefit of advances associated with the Canadian nonferrous mining industry overall?

Table 18

AVERAGE BENEFIT OF ADVANCES IN PIT SLOPE TECHNOLOGY FOR A NONFERROUS OPEN PIT MINE: METAL PRICE VARIANTS

		Increase in Ore Reserves	
	Reduction in Waste Excavation	Fixed Capacity	Variable Capacity
Increase in Before-Tax Cash Flow ($ million)			
Lower limit prices	22.5	15.2	24.9
Most-likely prices	22.5	74.9	84.6
Upper limit prices	22.5	165.5	175.2
Increase in NPV at start of development ($ million)			
Lower limit prices	9.9	5.4	8.1
Most-likely prices	9.9	14.8	31.8
Upper limit prices	9.9	31.6	68.9

Table 19

AVERAGE BENEFIT OF ADVANCES IN PIT SLOPE TECHNOLOGY: INCREASE IN CASH FLOW PER TONNE OF NONFERROUS ORE MINED ($)

	Improvement in Pit Slope Angle		
Metal Prices	2 Degrees	5 Degrees	10 Degrees
Lower limit	0.07	0.16	0.30
Most-likely	0.19	0.45	0.83
Upper limit	0.37	0.88	1.63

Table 20

EFFECTIVE TAX RATES FOR BENEFITS OF ADVANCES IN PIT SLOPE TECHNOLOGY

Metal Prices	Effective Tax Rate (percent)
Lower limit	44
Most-likely	50
Upper limit	53

One method would be to combine the evaluation of benefits per open pit mine with an estimate of the number of mines operating. There are presently about 20 nonferrous open pit mines operating in Canada. If this is assumed to be a long-term steady-state condition, the most-likely potential total benefit, expressed as a present value in 1982, would be:

$$(9.9 + 14.8 + 31.8)(20)/3 = \$377 \text{ million}$$

This is not in fact a very meaningful approach because the average size of ore reserves and average capacity of the 80 open pit mines in our data base are much lower than those of the 20 open pit mines currently operating.

To correct for this bias, potential benefits are converted to a per tonne of ore mined basis as presented in table 19. These benefits represent the increase in cash flows associated with advances in pit slope technology during the past decade, for each tonne of ore as it is mined.

The present productive capacity of the nonferrous open pit mining operations in Canada, as outlined in chapter 3, totals about 110 million tonnes of ore per year. If this now can be regarded as a long-term steady state condition, the most-likely potential annual benefit associated with the nonferrous sector would be:

$$(.45)(110) = \$49.5 \text{ million per year}$$

This would give a most-likely total benefit in 1982 present value terms of:

$$49.5\ (\text{CPVF}) \quad = \$619 \text{ million}$$[48]

More generally, a risk analysis has been carried out on the ranges of possible benefits depicted in table 19. Results of this analysis are presented in figure 17. The distribution of potential total benefits associated with advances in pit slope technology in the nonferrous mining industry during the past decade is quite skewed and highly uncertain. The expected value (EV) is $797 million compared with the most-likely value (MV) of $619 million. The 90 percent lower limit (LL) and upper limit (UL) values

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[48] CPVF: cumulative present value factor.
Here we ignore benefits realized up to the present time but extend the time distribution of benefits indefinitely. These two factors tend to cancel each other.

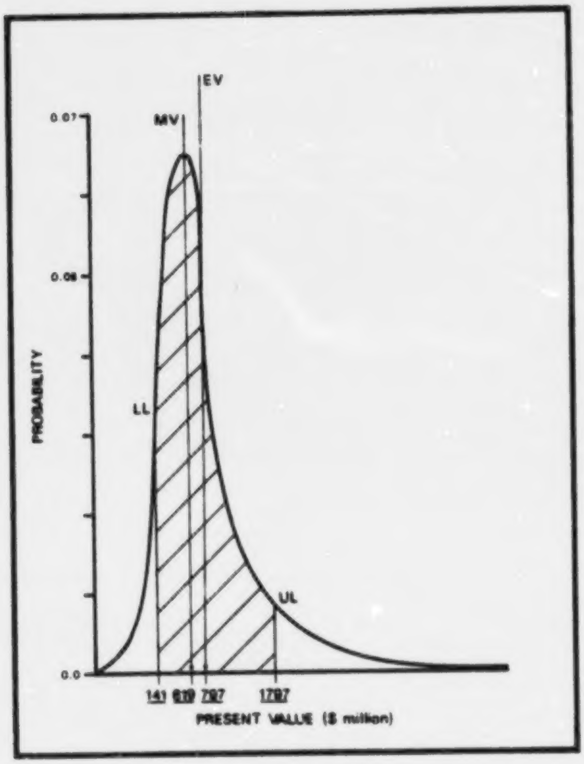

Figure 17.
Potential Benefit of Advances in Pit Slope Technology for the Nonferrous Mining Sector

are $141 million and $1,797 million respectively. This extremely wide range of possibilities reflects the high degree of uncertainty which exists concerning both metal prices and the average improvement in pit slope angle.

Finally, with regard to taxation effects, effective tax rates have been evaluated for the incremental benefits associated with improvements in pit slope angle and are presented in table 20 as a function of metal price. This evaluation is based on current federal and provincial tax regimes and assumes, once again, that one-third of the potential benefits are realized from each of the three specified alternatives for realizing benefits from steeper pit slope angles.

The effective tax rates assessed can be used to apportion overall potential total benefits between industry and government. For example, the most-likely social benefit of $619 million would be divided evenly: $309.5 million to industry in the form of higher after-tax cash flows, and $309.5 million to government in the form of increased federal and provincial tax payments.

NONFERROUS DEPOSITS MINEABLE BY OPEN PIT METHOD

New Brunswick

Brunswick 6
Clearwater *
Halfmile Lake *
Murray Brook
Third Portage Lake

Quebec

Anglo American
Barvue *
Bell Allard
Detour A1
Dumont
Grandroy
Louvem
Magusi *
Renzy

Ontario

F Group *
Great Lakes Nickel
Kidd Creek *
Mattabi *
McWatters *
Sturgeon
+ 1 nickel deposit in Sudbury basin

Manitoba

Maskwa West *
Ruttan *
+ 3 nickel deposits in Thompson belt (one *)

Yukon

Casino
Cowley Park
Faro
Gem
Grum *
Little Chief *
Minto
Swim Lake *
Vangorda *

British Columbia

Adanac
Afton *
Bell
Berg
Bethlehem
Boss Mountain *
Brenda
Caribou Bell
Catface
Craigmount *
Endako
Galore Creek
Gibraltar
Granisle
Harper Creek
Highmont
Huckleberry
Ingerbelle
Island Copper
Kitsault
Kutcho Creek
Lornex
Lynx *
Maggie
Morrison
Red
Red Mountain
Robb Lake
Sam Goosly
Schaft Creek
Sustut
Valley Copper

Northwest Territories

Bear Twit
Coronet
Eclipse
Gayna River
Great Slave Reef
Indian Mountain
Izok Lake
Pine Point 1
Pine Point 2
Pine Point 3
Pine Point 4
Pyramid
Redstone

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*initially mined by open pit, then by underground methods

APPENDIX VI

SELECTED COMMENTS RELATING TO THE BROADER SPHERE OF BENEFITS

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CANADIAN MINING INDUSTRY

Retrospective Justification

There was definitely a need for the Pit Slope Manual in order for the mining industry to become aware of slope stability. The technical level at the time of the manual was so inadequate at some mines that it was disastrous. There was a very wide gap in applied slope technology between good and bad mining operations.

(university-based civil engineer)

The CANMET manual definitely added to slope stability awareness. From 1970 onwards, as a result of seminars and conferences, people started asking questions. The 1971 and 1972 international conferences on stability in open pit mining helped with awareness. However, in 1972 Don Coates and CANMET took the lead. The manual was a good idea.

(geotechnical consultant)

Until the CANMET manual was published there was only a scattered series of papers. CANMET realized this and knew that the Canadian mining industry could progress if CANMET put all this information together. Until then, the Canadian mining industry had little appreciation for rock slope engineering. The CANMET manual formed a base, a philosophy. The project provided a think tank, bringing experts and practitioners together.

(geotechnical consultant)

There was a large amount of information generated in the 1970s concerning pit slope technology, but it was not available to mine operators. It was mainly in the hands of geotechnical consultants. The Pit Slope Manual provided a mechanism for this technology to be transferred.

(nonferrous mine developer)

You may be interested that, as consulting engineers, our assessment of the general field of slope stability is that it has progressed from almost total confusion and uncertainty in the 1960s to a situation which could be crudely classified as routine today. Consequently the role of universities, government institutions and consulting engineers has (or at least should have) changed markedly in this time. I raise this question because I believe that it was entirely appropriate for CANMET to establish the pit slope project in 1972 but it would be entirely inappropriate for it to initiate a similar project today. This does not mean that all the problems have been solved but I would not like readers of your report to gain the impression that these problems are such that another similar project or even a major rewrite of the manual is urgently required. You may consider these remarks to be obvious and even naive but I am constantly amazed at the straws which are grasped by planners in an attempt to justify one activity or another.

(geotechnical consultant)

Increased Awareness

The CANMET manual raised awareness. It brought consultants and industry together and provided the grounds for technical exchange. A lot of development of ideas concerning slope stability came through these exchanges, which constituted a type of think tank.

(geotechnical consultant)

Five years ago all open pit walls were designed at 45 degrees but presently a pit optimization is always done. An awareness of pit slope stability arising from the CANMET project has been a major factor contributing to this change.

(nonferrous mine operator)

The Pit Slope Manual aided in the increased awareness of rock mechanics and slope technology in 1976. This awareness was low prior to 1975, then it skyrocketed. The biggest benefit to the mining industry is that it obtained a standard reference text. No question about it, the manual is useful and it was $5 million well spent. The government did a good job. Prior to publication of the CANMET manual, the only basis for solving slope stability and design problems was to visit other mining operations and learn about what they were doing.

(nonferrous mine operator)

The CANMET pit slope project and manual helped mines address slope stability issues earlier than would otherwise have been possible. The manual increased awareness at the management level that rock slopes are not all 45 degrees. In the early seventies mines were at a loss as to who to contact or what to look for when they had a slope problem. The CANMET manual brought slope stability to the foreground for mine managers and created an awareness that slope stability is an integral part of the operation.

(asbestos mine operator)

General Benefits

The main benefit of the Pit Slope Manual is that it gives an engineer with no background in mining a source that will guide him in the right direction. It helps to delineate slope stability problems and the steps to follow for their solution.

(coal mine operator)

One thing the CANMET manual brought out that was not in the forefront before is the idea that 'one can design and live with failure'. The manual states that an open pit is poorly designed if it has no slope failure.

(nonferrous mine operator)

I believe the CANMET pit slope project has had a beneficial effect on pit slope design. It is certainly used by both staff of mining companies and geotechnical consultants. The principles embodied in the manual are also applicable to civil engineering slopes. However, in my experience the CANMET manual is not commonly used directly for this purpose. Nevertheless, the broad effect of the manual is a positive step for demonstrating Canadian expertise.

(geotechnical consultant)

The CANMET project and manual have encouraged a more quantitative approach to the design and analysis of slope stability. The availability of such material in one publication has provided a basis for developments and improvements in slope design and analysis.

(university-based mining engineer)

The CANMET manual was definitely required at the time. It is still one of the few manuals attempting to answer questions. The manual is used more often with time, and more people are using it.

(geotechnical consultant)

The Pit Slope Manual provided an impetus for open pit mines to employ full time staff responsible for rock mechanics. The manual was not directly involved in mine geotechnics at our operation but it laid a cornerstone to build on. The manual convinced the mining industry that rock mechanics is not in the kindergarten stage and is not an academic exercise but, rather, is a practical tool. The conceptual contribution of the manual in this area is its most important benefit.

(nonferrous mine operator)

The CANMET manual is a good reference. The money was well spent since it provides the non-specialist with a knowledge of when a geotechnical consultant is required. The manual is definitely required since it is a complete text and is understandable to non-specialist mine operators.

(iron ore mine operator)

The Pit Slope Manual brings everything together, providing conceptual ideas which can then be put into practice. It is a concise and valuable reference. The manual is a good check and is part of one's development as a professional.

(nonferrous mine operator)

The major benefit of the CANMET manual is that it standardizes slope design at mines. The manual established a convention. It may or may not be the best but mines generally adhere to it. Consequently, because of the high turnover at mines, information and analysis procedures are standardized, even without staff continuity. Also, the manual tells you when to call in consultants.

(coal mine operator)

The main benefit of the CANMET manual to us is that it provides a framework to collect data and process it.

(iron ore mine operator)

Specific Benefits

We started to use the Pit Slope Manual in 1976, and it has been used at the same rate since then. It is referred to when there is a slope stability problem. We wouldn't want to be without it. The manual is a useful way to transfer technology to open pit mining practice.

(asbestos mine operator)

The main contribution of the CANMET manual is in terms of increased safety. The monitoring chapter helped to insure union and management awareness of safety in terms of slope stability.

(nonferrous mine operator)

The Pit Slope Manual has helped us to understand and review our consultants' work and reports. The manual is an excellent way to transfer technology to open pit mining practice, especially for the non-specialist engineer.

(asbestos mine operator)

The Pit Slope Manual has had a conceptual influence on pit slope design changes but is not used in analysis. Hoek's Rock Slope Engineering is used for the latter purpose. The manual helped in the early stages of understanding slope failures.

(nonferrous mine operators)

The CANMET manual has been accepted and is applied by our company. The monitoring chapter is used most often, and was the basis for the monitoring system installed in 1977.

(asbestos mine operator)

We have found that the Pit Slope Manual is a valuable reference for underground as well as open pit operations, particularly with regard to mechanical support.

(nonferrous mine operator)

I am on the board of review for a tar sands project where there has been extensive use of concepts and principles in the Pit Slope Manual. Without, for example, good control of monitoring on that project, the mine would probably not be operating now because of serious failures that would otherwise have occurred.

(geotechnical consultant)

The single most important thing the CANMET manual did was to encourage the routine monitoring of open pit walls. Prior to publication of the manual in 1976, monitoring was not accepted or practiced throughout the mining industry as it is today.

(geotechnical consultant)

The CANMET manual is used as a reference about three times per year, particularly the ground water chapter. It is a good reference but more geared to the mine operator then to civil engineering applications. I like the manual because it is simple to use.

(construction-based civil engineer)

The reason why the Pit Slope Manual is not used more at the feasibility study stage is that government agencies require the technical design to be done by consultants. Nevertheless, the manual is a good check on the work of geotechnical consultants. It also allows managers who have been away from operations to refresh their understanding of pit slope design. We use the manual as a reference while doing feasibility studies, even though the actual design is done by consultants.

(nonferrous mine developer)

The monitoring system which was implemented here as a result of our involvement in the CANMET project is used more as a watchdog. It is a 'safety' approach rather than a 'steepening of wall' approach.

(nonferrous mine operator)

The main benefits of the CANMET project for us were with regard to monitoring, determination of strength parameters, stress measurements, and a finite element study and computer analysis which helped predict the interaction of our open pit and underground operations.

(nonferrous mine operator)

Potential Benefits

We are presently trying to sell slope stability analysis to management. It is estimated that if we are able to steepen a 5000-foot-long pit wall by two degrees, there would be a saving of $4 million in waste excavation and a benefit of $4 million in increased ore recovery. We would attribute 10 percent of these benefits to our use of the Pit Slope Manual.

(iron ore mine operator)

We have never heard of the Pit Slope Manual. There is a definite need for the manual but there is little awareness of slope stability analysis here yet. No instability problems have been encountered and the final walls are not yet cut.

(iron ore mine operator)

Our open pit operation has had no failures to date. I believe this is because we are operating at too flat a pit wall angle.

(iron ore mine operator)

There is a feeling that the characteristics of coal mines are generally sufficiently different to preclude application of the Pit Slope Manual. I would point out that this is an opinion of the coal mine operators themselves. If they were familar with the chapters in the manual, for example those which concern blasting, groundwater, and monitoring, they would find the concepts just as applicable to open pit and strip coal mines as they are to metal mines.

(geotechnical consultant)

We have been aware of the CANMET manual since 1976. Our open pit walls are designed at 45 degrees, based on past experiences. Slope stability studies have not been carried out here because there is no perceived benefit. A presentation has been made to management on how to approach slope stability analysis with a modest budget. Potential benefits might be possible from steepening the hanging wall of the pit.

(iron ore mine operator)

Open pit mining in our province is restricted to coal mining under strong clay and till overburden, and one hardrock uranium mine. There are only marginal problems with stability at these operations and the full potential of techniques described in the CANMET manual have not been necessary. Deeper workings at both the coal mines and future uranium mines will require more sophisticated engineering techniques.

(mine inspector)

The coal industry is ten years behind the times in terms of geotechnical practice. Rock slope practice in hard rock open pits is much more advanced. There is a need for improvement in coal industry practice. The Pit Slope Manual is applicable to coal, particularly the chapters on structural geology, monitoring, blasting, and reclamation.

(coal mine operator)

In the 1972-81 period, all of our quarries were either in an early stage or wide enough not to require multi-benching. But, since 1981 the situation has evolved so now three or four of our operations will require slope studies. I plan to follow the procedures proposed in the CANMET manual.

(non-metallic mine operator)

GOVERNMENT REGULATION

In our province, mine safety legislation has not been altered to date but it may become advisable to issue a 'Code of Practice' based on the Pit Slope Manual. A 'Code of Practice' would require mines to become familiar with the techniques that are available in the manual to solve slope stability problems.

(mine inspector)

Our mine inspectorate suggests to mining operations that the Pit Slope Manual would be beneficial but we do not have control of direct usage. There is no doubt that more use could be made of the manual.

(mine inspector)

As far as major changes to our mine inspection program, we established a ground control engineer's position to provide technical expertise in rock and soil mechanics problems partly as the result of the awareness created by the CANMET project.

(mine inspector)

In our mine inspectorate, the Pit Slope Manual is a reference which is used continually, as our inspectors indentify slope stability problems taking shape during field inspections.

(mine inspector)

If an open pit mining operation follows the procedures recommended in the CANMET manual, we would accept the work as being good engineering practice.

(mine inspector)

I use the Pit Slope Manual as a reference, the reason being that it is in condensed form and easy to read. I know that most of the manual's contents existed previously in some form or another but now it has been put together in one comprehensive reference. The value of the manual is that it is a quick reference to find out if mines are telling the truth.

(mine inspector)

GEOTECHNICAL CONSULTANTS

I do not believe our company concepts, procedures or analyses are directly attributable to the Pit Slope Manual. Our staff are generally highly trained specialists who have developed a broad and detailed understanding of the subjects covered in the manual. The manual serves therefore more as a reference for our professionals and junior staff.

(geotechnical consultant)

Procedures and analytical techniques presently in use in our firm which are attributable in some part to the CANMET pit slope project include the following:

- discontinuity mapping techniques and data analysis;
- some movement instrumentation techniques;
- some groundwater instrumentation techniques;
- some field sampling procedures;
- factors of safety used in the analysis of waste dumps for varying conditions.

In all the above, the concepts, procedures and analytical techniques in use are traceable in part to the pit slope project but also to a number of other sources including in-house development.

(geotechnical consultant)

I make use of the entire Pit Slope Manual for a variety of purposes in connection with my consulting work. Frequency of use appears to be more or less constant with time.

(geotechnical consultant)

The CANMET pit slope project was a valuable and useful exercise, particularly for the companies actively involved in the research which went into its preparation.

(geotechnical consultant)

The CANMET project provided me with a vehicle to become established as a geotechnical consultant in Canada. It extended my education and qualifications and, generally, improved our knowledge pertaining to slope stability. The pit slope project gave recognition to Canadian consultants, both domestically and internationally.

(geotechnical consultant)

I have made use of the procedures given in the Pit Slope Manual to assist in my consulting work. A recent example was use of information on tailings deposits in the Timmins area. I would say that I have made reference to various sections of the manual two or three times a year since its publication.

(geotechnical consultant)

I derived important professional benefits from my work on the CANMET project. It is the reason why I am in the open pit consulting business. The CANMET project encouraged me to move from underground to surface mining. The project was very beneficial to the consultants that were involved, in terms of both knowledge and credibility.

(geotechnical consultant)

UNIVERSITY EDUCATION

The CANMET manual is part of our required third-year course on drilling and blasting, and is used particularly in laboratory sessions on wall control, vibration measurement, and monitoring.

(university-based mining engineer)

While I was head of mining engineering departments in Canada and Australia, the CANMET manual was employed as a teaching aid in rock mechanics and mine design courses.

(university-based mining engineer)

The Pit Slope Manual has been used as a reference in our rock mechanics course since 1979, particularly the chapter on mechanical properties. The monitoring chapter is used as a reference in our surveying course.

(university-based mining engineer)

In one specific technical area, that of the use of probabilistic methods of analysis, the CANMET project advanced my own professional 'technique'.

(university-based mining engineer)

I use the Pit Slope Manual as a teaching aid and recommend its purchase as a reference work in a graduate course - Slope Stability. I give the chapters on groundwater, monitoring, and mechanical support and structural geology as required reading.

(university-based mining engineer)

The Pit Slope Manual is used as a teaching aid but not as the required reference in courses given in our department. The main course concerned is 'Rock Slope Engineering'.

(university-based mining engineer)

I have not used the CANMET manual as a course requirement. Nevertheless, I advise my students of its existence and availability during lectures or discussions dealing with tailings disposal systems.

(university-based civil engineer)

I use some of the material from the Pit Slope Manual in my teaching and have also used some of the material in my consulting activities. In particular, the information involving mechanical support and groundwater investigations is very good.

(university-based mining engineer)

INTERNATIONAL SPILLOVERS

The Pit Slope Manual is generally regarded by my colleagues in the United Kingdom as an excellent and worthwhile reference manual and often used in conjunction with Rock Slope Engineering by Hoek and Bray.

(coal mine operator)

The effect of the CANMET pit slope project in my view has been a very favourable one in general terms. It has firstly served the purpose of making many engineers aware of the difficult facets of slope stability investigation. It has also been a useful reference to consultants in specific areas where they did not have the necessary expertise. It has not had a similar impact in civil engineering construction in South Africa and is relatively unknown by the civil engineering practitioners of rock mechanics.

(geotechnical consultant)

A number of concepts and procedures that were put forward in the Pit Slope Manual are being used in our practices in South Africa for the design of rock slopes for open pit mines. In particular the sections on risk analysis and monitoring techniques are commonly referred to. We have made extensive use of the joint interpretation programs, the risk analyses concepts, the perimeter blasting section, and monitoring concepts for the purpose of rock design in open pits and surface cuttings.

(geotechnical consultant)

Two-thirds of the mine inspection branches in the United States are using the Pit Slope Manual to assist with mining regulation.

(geotechnical consultant)

The CANMET manual is extremely useful for training and induction of engineering staff. For surface mining in the United Kingdom there is a tendency (in my opinion, an unfortunate one) to employ civil engineers rather than mining engineers in surface mining. Often they have little appreciation of mining techniques and hence training courses are given in blasting, geotechnics, groundwater, dewatering, pollution, etc. The CANMET manual is used in this training process.

(coal mine operator)

The concepts, procedures and analysis techniques applied to our teaching and research could not be exclusively attributed to the Pit Slope Manual. However, we have found the manual to be a useful single reference source for our students. The manual is used as a general student reference for our rock mechanics course in the final year of the mining engineering program.

(university-based mining engineer, Australia)

The third international conference on stability in open pit mining provides clear evidence of the contribution that CANMET's pit slope project has made to the advancement of pit slope technology. Examination of the proceedings indicates contributions attributable to the project in terms of contributing authors, case studies, acknowledgements and references.

(geotechncial consultant)

With reference to the relevance and use of the CANMET Pit Slope Manual, there are four basic types of surface mine in Australia:

- large open pit iron ore mines, mainly in Western Australia;
- shall open pit bauxite mines in Queensland and Western Australia;
- single-seam open strip black coal mines, mainly in Queensland;
- large open pit mines in sedimentary rocks, such as the brown coal mines in Victoria and the proposed oil shale mines in Queensland.

The Pit Slope Manual is generally applicable to the open pit iron ore mines, but does not address some major factors in pit design for the black and brown coal mines. The nature of the bauxite deposits (surface laterites) makes slope design irrelevant, except for the design of tailings dams. The majority of nonferrous metalliferous mines in Australia are underground operations, and the Pit Slope Manual is useful for tailings dam design in those cases.

(government-based research officer)

BENEFIT BARRIERS

A significant disadvantage of the Pit Slope Manual is that it does not specifically address problems in coal mining, which form a significant fraction of consulting engineering problems for the mining industry in western Canada.

(coal mine operator)

The monitoring chapter from the CANMET manual has been used at our coal mine to develop a highwall monitoring program. The case studies in the manual have been looked at and the situations (accelerated movements) that may arise prior to failure. The rest of the manual hasn't been used since it is not applicable to coal workings in steep terrain. The manual assumes flat terrain and hard rock conditions. The failure modes are quite different in sedimentary rock, especially the extremely faulted types encountered here.

(coal mine operator)

In hard rock mines, flattening wall angles is an acceptable way to stabilize slopes. This is not necessarily so in coal measures.

(coal mine operator)

Virtually nothing written on surface geotechnics applies to coal mines. Coal measures are between soil and rock. The Pit Slope Manual is not applicable.

(coal mine operator)

I do not think the CANMET manual has had significant influence on rock slope design and control in civil engineering construction.

(construction-based civil engineer)

From the civil engineering viewpoint, the Pit Slope Manual has limited value simply due to the different design philosophies involved in civil projects and open pit mining. Unlike mining, the civil field is not as concerned with the strict economic constraints of optimizing stripping ratios, estimating probabilities of bench failure, etc. Most of the civil rock work companies base their design approaches on minimizing any failure in order to protect their installations or the public from rock fall hazards.

(construction-based civil engineer)

Geotechnical consultants have been involved in slope stability studies at our mine since 1970 when a major overburden slide occurred. Thus, the CANMET manual came too late for us. By the time it was published we, with the help of our consultants, had already carried out slope stability studies and developed operating procedures.

(asbestos mine operator)

The benefit to our operation of the CANMET pit slope project and manual was negligible. The only direct contribution made was in a telephone conversation when we were informed that an electronic theodolite we were about to purchase would measure to the accuracy required by us.

(nonferrous mine operator)

We haven't used the Pit Slope Manual. Our slope design is done through experience. The last time a geologist was here to look at rock problems was in 1969. The manual is too technical and research oriented.

(nonferrous mine operator)

Regarding certain technical discrepancies published in the Pit Slope Manual on our theodolite, we must assume that a very outdated model was used for this specific test. It is unfortunate that this mis-representation of our equipment in the manual has influenced the choice of alternative equipment by two mining concerns in Alberta. We feel that we must take some exception to the obvious favouritism which is shown toward a competitor's product. Our concern in this regard would be that possible erroneous information contained in the manual could result in a false impression on the part of the user, and, of course, lost sales for us. This happened on several instances to our knowledge.

(open pit supplier)

In 1975, as part of the CANMET project, our mine was used as a case study. A slope stability study was carried out and, as a result, our pits were divided into domains. There was no benefit to the mine from this work. It didn't tell us anything.

(nonferrous mine operator)

We question the success of the CANMET project in making open pit operations safer and more profitable. It may be that some of the work carried out was impractical, but discussion with our local Inspector of Mines indicates that, at many mining properties, pit slopes are not regarded as important. The managements of these properties only pay lip service to any manual, no matter how good.

(nonferrous mine operator)

APPENDIX VII

SELECTED COMMENTS RELATING TO PROJECT, MANUAL, AND TECHNOLOGY TRANSFER CRITIQUE

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PROJECT IMPLEMENTATION, SCOPE AND STRUCTURE

It was important to have consultants involved in preparation of the Pit Slope Manual since they are the main salesmen to the mining industry and they are the best ones to introduce new technology to the mines.

(university-based civil engineer)

There was too much money spent in the CANMET project for condensation of existing material and too many people were involved. CANMET should have been able to do the study for a lot less than $5 million. It overdid the use of consultants. Mining companies could have done equally well. There was a need to get the mines more directly involved.

(mine inspector)

In order to undertake such a study, one must ensure ideas get well ventilated among practioners. Unfortunately, the CANMET manual does not reflect the state of the mining industry. The group of people that should be involved in the study should be practioners. Get people who are faced with everyday problems (the pit operators) and give them a larger role in the work.

(geotechnical consultant)

The overall concept and organization of the Pit Slope Manual was good and the work framework is good. The problem arises when the work is completed and the project team disbands. Unless the manual is marketed, maintained, and updated, we will lose a good thing.

(university-based civil engineer)

There is no winning way to go about this type of study. One alternative would be to do it in-house, but it would be hard to have the right people involved if it was an exclusive government venture. A second alternative would be to have one consultant do the study. However, this would result in a biased product.

(geotechnical consultant)

The editing process was really frustrating. The reports had to be rewritten. There should have been a larger editorial staff to help formulate the final draft.

(geotechnical consultant)

The mining industry was highly suspicious of government and it was with extreme difficulty that we in the consulting field were able to involve mining companies in talking about case examples. The mining industry simply does not like to air its 'dirty linen' in public. Another reason that they were reluctant to join in the project is that some of them simply couldn't spare the staff for the work involved.

(geotechnical consultant)

CANMET did a good job in management of the project. The government is more suited to do this type of study.

(geotechnical consultant)

The fundamental problem with the CANMET project was that it was not coordinated properly. It would have been better if in each subject area there was a government representative who coordinated the technical work rather than participating solely at the management level. Consequently, the manual is a collection of research projects which lack integration.

(geotechnical consultant)

The individual researchers were pushing their own ideas and opposing ideas were not documented. For example, there are two opposing blasting concepts. One got the CANMET contract, and the other is not referred to in the manual.

(geotechnical consultant)

Many of the personnel involved in the CANMET project, including some consultants and universities, did not have the expertise to develop such a manual. The mining industry now on occasion has to pay for their services. It is hoped that the more ebullient members of the consulting industry can be prevented from taking over any new project entirely.

(nonferrous mine operator)

The CANMET project was a good, imaginative concept. There were problems in coordination and integration due to its broad scope and the contracting out process. In the end, there was a lack of follow-up in selling the product to mine operators.

(university-based mining engineer)

Staff members of CANMET reviewed all of the chapters. However, this review was extremely heavy handed and in the one instance in which I was involved, the chapter was so extensively rewritten that we advised CANMET we wished to have no further involvement on the chapter.

(geotechnical consultant)

The demand for the CANMET project should have come directly from the mining industry--if the industry didn't recognize the demand in the first place, the demand should have been stimulated. But, coming from them would have insured its eventual success and acceptance. At its inception, the project had input from consultants, suppliers and universities, but open pit mine operators by and large didn't participate.

(university-based mining engineer)

I do not think that the $5 million investment in the CANMET project was well spent, in the sense that it could have been done for much less.

(university-based mining engineer)

An attempt to join in the CANMET project in a meaningful way was made by our mine and was rebuffed in the most cavalier fashion. We would like to point out that this proposal formed the basis of our pit wall investigations. Some 8 years later the work proposed and carried out by us, independent of the CANMET project, can be seen to be a practical least-cost approach to the problems. Although we have a small, low grade, marginally profitable mine, we feel we have done proportionately far more for the industry than the Pit Slope Manual. This has all been accomplished on site without the use of consultants or external funding, and is the result of a forward-looking board of directors and management encouraging the staff and workforce. We would estimate that the expenditures in equipment for pit slope work here would total about $200,000 and the costs of internal labour equal that amount. This work paid a return in 1978/79, when a million tonnes of high grade ore were mined at relatively high metal prices under a failing pit slope, and over a failing haul road. That area is now being approached by our latest pit expansion at metal prices far from satisfactory, and would give us a much smaller return on our investment if mined under present conditions.

(nonferrous mine operator)

Mine operators should have been more closely involved in the CANMET project, to stress the practical point of view and learn from their experiences. Thus, the manual would have been more geared to the mine operator who has to put it to work.

(nonferrous mine operator)

A major deficiency of the program was that the selection committee was entirely made up of government people. There should have been a number of external mining representatives and consultants on this committee. The reason I say this is that the CANMET people who were involved in the program had relatively little practical engineering experience with respect to the research project.

(geotechnical consultant)

Our staff attended meetings with CANMET in the early stages of the project. However, management decided not to participate because the mine already had consultants involved in pit design, they were suspicious of government, and they did not want to follow government guidelines for project implementation and presentation.

(asbestos mine operator)

One of the major complaints of the consulting engineers which were involved was that the rates that were finally negotiated with the government were actually below cost, and as a result of this, the incentive to make the research program as comprehensive as possible actually was lacking.

(geotechnical consultant)

THE CONTRACTING-OUT PROCESS

Selected comments relating to contracting-out aspects of the CANMET project are included in the previous section. Here we provide a summary of an internal CANMET review of the research and development performance associated with this contracting-out process.[49]

Qualitative judgment of in-house CANMET staff was used to establish the level of performance and quality of output experienced in contracting aspects of the CANMET pit slope project. Scientific officers were asked to grade contracts for which they had direct supervisory responsibility. The purpose of the review was to grade each contract performance, relate performance to its cause, and derive any implications for the practice of contracting.

Overall, performance ratings of contractors shows 31.9 percent of all ratings as 'commendable' performances and 55.7 percent as 'acceptable' performances, with the level of 'unacceptable' performances at 12.4 percent of all ratings.

Of particular interest is the account of poor performances. There were indications in the review that the main unfavourable features were: insufficient allocation of physical resources to the task, inadequate managerial ability of the contractors, professional incompetence on the part of contractors in some fields, and lack of cooperation with CANMET. To a lesser degree, CANMET's definition of the task to be performed was admitted to be vague and this undoubtedly contributed to misunderstanding on the part of contractors as to the purpose and requirements of the task.

The review attributed the following causes to unacceptable performances:

i a manufacturing firm developed a resentment to the direction which the task took, possibly feeling it would indicate or imply defective products of its manufacture;

ii a mining company ran into economic difficulties which curtailed production and terminated its involvement in the project;

iii a contractor placed excessive emphasis on publishing early results under his name, forcing CANMET to terminate the contract;

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[49] Pit Slope Project - a Case Study of Contracting-Out, G. Bartlett and D.F. Coates, Report 78-17, CANMET; Energy, Mines and Resources Canada; Ottawa, September 1978.

iv in two cases, contractors were found to be incompetent for the required task or lacked essential equipment.

The review found that the following factors contributed to less-than-expected levels of performance:

i contractor placed direct income ahead of quality of work;
ii contractor lost key personnel during course of the contract;
iii CANMET's demands exceeded initial agreement;
iv contractor ran into financial trouble;
v contractor involved himself with other clients to the detriment of the project;
vi a university staff member failed to distinguish between the performance requirements under a contract and those under a research grant;
vii contractors failed to present data in the format and style prescribed by CANMET for the manual, in part due to CANMET's delay in issuing formal guidelines.

DESIGN PHILOSOPHY

The Pit Slope Manual did not succeed in developing a set of programs that one can use for pit slope design.

(geotechnical consultant)

The probabilistic nature of slope failure was pushed into the manual and should be redone because it is poorly done.

(mine inspector)

The pit slope manual's concept of probability is too exaggerated. The 'factor of safety' approach is not even mentioned and it is the more proven technique.

(geotechnical consultant)

The design chapter is very difficult to read and there is some argument as to its usefulness. A balance is required between 'factor of safety' and probability approaches. A philosophy of design is lacking.

(geotechnical consultant)

The Pit Slope Manual is too oriented to probability. Although it is a good tool, most of the time a simpler approach will do. For the design of an entire wall, probability analysis is required. However, in analyzing a localized failure, a simpler 'factor of safety' approach is adequate.

(nonferrous mine operator)

The philosophy of design is useful for educating clients on what slope design is all about. We have found the CANMET manual very useful for management and engineering staff as an education tool. I recommend that clients read certain sections of the manual prior to meeting with them. Because it is a government publication, it has authority.

(geotechnical consultant)

In the opinion of our engineers on staff, the Pit Slope Manual is very well-written and somewhat unique in the way all the necessary information is presented. However, one criticism of it is the replacement of 'factors of safety' by 'reliability analysis' which poses some problems to engineers of the older school. It might have been better if both 'factor of safety' and 'reliability analysis' were used in computing slope angles.

(mine inspector)

The manual dwells too much on a probabilistic approach to stability. I feel that the old factor of safety approach which we incorporate in all our computer programs is a far better method which is easier for operators and senior mining personnel to comprehend.

(coal mine operator, United Kingdom)

I don't agree with the emphasis placed on probabilistic reliability analysis. Many would agree with me that this is one of the negative aspects of the Pit Slope Manual. Since it is impossible to quantify all of the parameters affecting pit slope design, statistical analysis of available data is inappropriate. Engineering judgement and experience are major factors in developing an appropriate design.

(university-based mining operator)

With regard to the probabilistic reliability analysis procedure, I would point out that only one or two rock mechanics engineers of any national repute utilize this method. The majority of recognized rock mechanics and stability engineers still use the conventional safety factor method. The probabilistic approach has merit where we are dealing with pit slope failure that is totally controlled by structural geology and we can use the probabilistic approach to evaluate the likelihood of the occurrence of controlling structure. But where the failure is going to occur along a known failure surface we can predetermine, the standard safety factor method is the best procedure to use. Those of us who use the safety factor approach of course have had extensive experience. When we select the value of the strength to use, we are utilizing our own reliability approach to the selection of that value. I would also point out that the selection of the probability curve is also a best-guess situation based on information which is available and which may not be complete. In conclusion, the use of the probabilistic reliability analysis procedure is significantly over-emphasized in the Pit Slope Manual and any revision should take this into account. Most practitioners do not use it.

(geotechnical consultant)

THE PIT SLOPE MANUAL[50]

General

The Pit Slope Manual should have been advertised as an operating handbook rather than a manual. A manual should describe techniques. In no way should it take you to the final design.

(geotechnical consultant)

I have been involved in the last few years in research into the use of ground anchors for stability purposes, backfill settlement and blasting, and use the mechanical support and blasting chapters of the CANMET manual as a handbook.

(coal mine operator)

Our engineers comment that many of the chapters are very clearly written and can be easily understood by non-technically-trained personnel. The Pit Slope Manual is therefore very useful as an instructional tool.

(geotechnical consultant)

I think the most useful parts of the manual are the structural geology, blasting, groundwater, and waste embankments chapters.

(university-based mining engineer)

Perhaps in an exceptional case one would need the instrumentation and accuracies outlined in the CANMET manual. However, in terms of the norm for everyday operations, the manual is too complex and fancy. One generally requires accuracies much less than stated in the manual, i.e. a Volkswagon is required instead of a Cadillac.

(nonferrous mine operator)

The Pit Slope Manual is too long, repetitive, and requires condensation. Since each chapter is written individually and stands alone, there is too much overlap.

(iron ore mine operator)

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[50] Also see appendix VI, especially 'Specific Benefits, Canadian Mining Industry'.

A comprehensive index is required.

(iron ore mine operator)

The Pit Slope Manual is employed extensively at our mine. The chapters of most use are design, monitoring, and blasting. The other chapters are not used because the mine doesn't have problems in these areas.

(nonferrous mine operator)

We have a number of complete sets of the manual in our organization, some of which belong to the company and some to individuals. The chapters on waste embankments, monitoring, buttresses and retaining walls, blasting, and groundwater are used perhaps most frequently, (once or twice per month).

(geotechnical consultant)

How does Hoek manage to get everything into one book whereas the CANMET manual requires 27 volumes?

(nonferrous mine operator)

Our general opinion of the manual is that it is good as a general reference. The case histories are the best part of it. We would like to see further case histories.

(nonferrous mine operator)

In my opinion, the Pit Slope Manual contains information and data that are irrelevant, incorrect, incomplete or unreferenced. Although many references are given throughout the text, references have not been given for many important statements, figures and tables.

(university-based civil engineer)

The CANMET manual tends to be more 'modular', making for quick access, and is generally simpler to use than most textbooks on the subject.

(mine inspector)

Structural Geology

With regard to the structural geology chapter, procedures for gathering geological information for slope stability analysis are excellent; however, the manual fails to present comparative costs of obtaining the necessary data.

(geotechnical consultant)

We have mainly used the structural geology chapter. The chapter is too detailed for what is usually required. However, all the information is there if you need it.

(nonferrous mine operator)

Emphasis in the structural geology chapter should have been placed on major structures rather than minor structures. Major structures i.e. faults, can cause major slope problems but minor structures in most cases cause nuisance problems which don't require detailed line mapping techniques to solve.

(nonferrous mine operator)

The structural geology chapter is the best chapter in the manual but simplification is needed.

(geotechnical consultant)

We use the manual for structural geological mapping. However, the manual is very negative about the application of photogrammetry. Since our mine has faces 300 feet high with no berms, they can only be mapped using photogrammetry.

(iron ore mine operator)

The structural geology chapter is cumbersome and too geologically oriented. It should zero in on rock fabric.

(geotechnical consultant)

Mechanical Properties

I think the descriptions of the various rock tests and geotechnical investigation procedures in the chapter on mechanical properties are useful comprehensive references for any rock slope engineer.

(construction-based civil engineer)

The comments I receive on the mechanical properties chapter indicate that other reference material or advice of specialist consultants would have to be utilized in order to acquire sufficient background information to design the ultimate pit slope. The section itself is fairly theoretical.

(geotechnical consultant)

Groundwater

At the moment, I am involved in research into groundwater dewatering, and the pollution and general hydrogeology of the mining environment. I find the information in the groundwater chapter to be most useful.

(coal mine operator)

The groundwater chapter is considered to be particularly good since it describes specific equipment and procedures used in controlling the flow of ground water. The formulae and sample calculations are judged to be very useful.

(geotechnical consultant)

The groundwater chapter is weak on actual investigation techniques and evaluation techniques for operating mines. It is presently too concerned with a mine at the feasibility study stage.

(nonferrous mine operator)

With the exception of case studies, there is nothing in the groundwater chapter that is not available in books or references. However, if the object of the chapter was a compilation of references, then it is a good one.

(nonferrous mine operator)

Design

The basic analysis in the design chapter is good. However, the economic approach is very academic. Too many variables are involved. A practical approach is required rather than an academic one.

(nonferrous mine operator)

The design chapter is judged to be deficient, largely because economic criteria such as cut-off grade are not discussed.

(geotechnical consultant)

Regarding the design chapter, the ability to model pit slopes mathematically using computers has far out-distanced the ability to quantify the geological, strength and groundwater parameters which must be input to the programs. Therefore, the emphasis at the operating level should be on simplified analyses and design charts. High powered computerized analyses are best left to specialists and university types.

(nonferrous mine operator)

Mechanical Support

The mechanical support chapter is very specific in use. It is hard to justify application as a mass stabilization measure.

(geotechnical consultant)

Perimeter Blasting

The perimeter blasting is good, and its appendices are particularly useful references, although my own blast design approach differs from it somewhat. The only real oversight in this chapter is the lack of a 'Blast Evaluation and Optimization' section.

(construction-based civil engineer)

With regard to the perimeter blasting chapter, no work has been done on comparing results for various accelerometers and velometers. This must be done by someone soon. No work has been done on the depth of sensor burial or the types of shock wave being measured. No work has been carried out on the number of delays used versus the shock. This chapter should be rewritten.

(nonferrous mine operator)

Monitoring

The basic purposes of slope monitoring are i) to delineate areas of instability prior to rapid movements and ii) to allow remedial and/or precautionary measures to be undertaken once a slope movement has been located. The monitoring chapter of the CANMET manual has concentrated only on i) above by describing the hardware of monitoring. Not enough attention is given to the philosophy of monitoring. The most serious omission from the monitoring section is a comprehensive listing of slope instabilities monitored in open pits.

(nonferrous mine operator)

I have not made use of the monitoring chapter primarily because it appears to be garbled and inadequate.

(geotechnical consultant)

A major problem with the monitoring chapter is that it is far too theoretical and does not have sufficient practical consideration. In other words, some of the techniques outlined simply can't be used the way they are outlined.

(geotechnical consultant)

The monitoring chapter is quite comprehensive but it seems to focus strictly on the 'high-tech' monitoring methods. 'Cheap and dirty' monitoring methods which make clever use of materials on hand could be of great benefit to the mining industry.

(construction-based civil engineer)

Waste Embankments

I have used the waste embankments chapter to understand the basic concepts as well as for actual design. It is an excellent reference.

(nonferrous mine operator)

The waste embankments chapter is excellent and has been used by us. It is an excellent introduction to the mining community about how to revegetate.

(nonferrous mine operator)

The waste embankments chapter is very good but it now requires updating. It helped to identify the geographic importance of climate in reclamation.

(geotechnical consultant)

Computer Programs

The computer programs should be available on a more easily transferred medium such as IBM-type diskettes. With the increase in small computer usage, this would make transfer of programs very simple for most computers.

(nonferrous mine operator)

I have not used the DISCODAT program which appears to be excessively complicated.

(geotechnical consultant)

After extensive modifications, the DISCODAT computer programs have been used by one of the mines near here with some success, but it is too computer oriented and not sufficiently user oriented.

(nonferrous mine operator)

The DISCODAT programs are too detailed for daily operational use. We purchased the GEODAT program since it is simpler. The engineer will approach a problem with the detail that is required.

(nonferrous mine operator)

Without computer capability, the more sophisticated techniques have to be reduced/simplified for manual manipulation. We are unable to make use of the computer applications, which comprise the core of the manual. The manual is geared for computer analysis. We use references that can handle manual analysis, e.g. Rock Slope Engineering.

(geotechnical consultant)

Summary of Responses to Questionnaire by Canadian National Committee on Rock Mechanics

In 1979, a questionnaire was prepared by Dr. J. Franklin for the Sub-Committee on Rock Slopes, Canadian National Committee on Rock Mechanics, concerning use of the CANMET Pit Slope Manual. The questionnaire was sent to 125 users of which 40, or 32 percent, responded. The following is a summary of the replies received.[51]

i Do you know of the existence of the manual?

Yes	83%
No	17%

ii Has the manual been advertised

well?	12%
adequately?	48%

iii Do you think that the manual is on the whole

very useful?	30%
useful?	70%
of little value?	-

iv Do you think that the manual as a whole requires

extensive revision?	-
partial revision?	70%
is satisfactory without revision?	30%

v Opinions of the individual chapters.

Most useful (in order):	Perimeter Blasting
	Summary
	Structual Geology
	Groundwater
	Monitoring
	Mechanical Properties
Least useful (in order):	Design
	Mechanical Support
	Waste Embankments
	Environmental Planning

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51. See 'Report of the Sub-Committee on Rock Slopes', Canadian National Committee on Rock Mechanics, Toronto, May 1980.

vi Priority for revision (in order).

- Monitoring
- Design
- Perimeter Blasting
- Structural Geology
- Groundwater
- Mechanical Properties
- Mechanical Support
- Environmental Planning
- Waste Embankments

vii Specific comments by chapter.

Mechanical Properties:

- more emphasis should be placed on topics such as strength of jointed rock 'mass'.

Design:

- examples of actual pit designs should be mandatory;
- practical method of pit slope design should be included;
- should include other modes of failure - toppling, general slide surfaces, buckling and an introduction to concept of progressive failure;
- one detailed (complete) case history.

Perimeter Blasting:

- effect of rock types and structure on blasting techniques should be emphasized;
- more case histories should be included in the chapter;
- blasting practice and the prediction of fragmentation should be emphasized.

Monitoring:

- more examples should be included;
- this chapter should be updated.

viii General comments:

- if possible, combine all the chapters into one volume;
- the manual has been found to be a good teaching tool at several Canadian universities.

ix The following topics were suggested by the users for incorporating in the manual:

- practical aspects of pit design, haul roads, benches, etc.;
- more emphasis on financial aspects of pit design: cut-off grades vs stripping ratios;
- equipment requirements determination as an integral part of mine planning;
- stability of soil slopes;
- toppling failure mode and concept of progressive failure;
- effects of topography on slope stability;
- scaling practices and berm clean-up practices;
- effects of earthquakes on stability and induced seismicity due to blasting.

COMPARISON OF MANUAL WITH OTHER REFERENCES

As references, we use the Pit Slope Manual and Rock Slope Engineering each 50 percent of the time. Rock Slope Engineering is more practically oriented.

(nonferrous mine operator)

Our group is in the preliminary stages of mine developments in mountainous terrain. We find the Pit Slope Manual useful but Rock Slope Engineering is used most of the time since it was available first. Without a geotechnical background, an engineer needs the CANMET manual.

(coal mine developer)

The Pit Slope Manual is more detailed than Rock Slope Engineering. Design charts, such as used by Hoek, could be usefully employed in the CANMET manual.

(mine inspector)

The CANMET manual is more useful than Rock Slope Engineering and more applicable to open pit mining. We use the manual as a reference 80 percent of the time and Hoek 20 percent.

(geotechnical consultant)

We make much greater direct use of Rock Mechanics Principles by D.F. Coates than the CANMET manual in our rock mechanics course.

(university-based mining engineer)

I think the civil engineering field finds references such as Rock Slope Engineering to be more valuable than the Pit Slope Manual.

(construction-based civil engineer)

Most geotechnical engineers and engineering geologists involved in rock slope design and construction tend to use publications such as Rock Slope Engineering.

(construction-based civil engineer)

I believe the CANMET pit slope manual was primarily aimed at the mine operator rather than the academic and from this standpoint I do not believe it compares favourably with Rock Slope Engineering. I believe the manual is used more as a reference work.

(university-based mining engineer)

Since the CANMET manual is too long and has no index, Rock Slope Engineering is used as a quick reference.

(iron ore mine operator)

We use both the Pit Slope Manual and Rock Slope Engineering. The manual is more comprehensive but Hoek provides a good summary, especially if one has the requisite background.

(nonferrous mine operator)

The basic texts employed here are the Pit Slope Manual, Rock Mechanics Principles by Coates, the AIME slope stability conference proceedings, and Surface Mining by Leider. The CANMET manual is used most frequently since it is most directly oriented to pit slope stability.

(asbestos mine operator)

The Pit Slope Manual is a superior reference. I use it more often than any other reference manual, including Hoek's Rock Slope Engineering. Each aspect of pit slope stability has an entire chapter devoted to it.

(nonferrous mine operator)

The Pit Slope Manual contains much more detailed information than other references of this type. This is an advantage when detailed final designs and analyses are being made for a specific project.

(university-based mining engineer)

I am unaware of any other manual of similar scope, with the possible exception of the Civil Engineer's Reference Book. The reference book has the questionable advantage of being bound as a single volume. It is perhaps better arranged than the Pit Slope Manual in that the material is more uniform in format, more homogeneous in quality, and better indexed.

(geotechnical consultant)

UPDATING AND EXTENSION OF MANUAL[52]

As most parts of the Pit Slope Manual are now several years old I feel that updating it would be very valuable and hope that this will incorporate recent developments in mining as a result of the various research projects undertaken since the manual was first written. However, I must say that I feel that the manual is still, probably, the best reference work available for slope engineering, but I would like to see the work expanded to embrace other features of surface mining.

(coal mine operator)

Several suggestions are made that may be useful if a new manual is planned. Our engineers would like to see cost data included in the manual as this is most useful to the engineer recommending the choice between alternatives. Another suggestion is to update the technical content of the manual by including the results of recent research into slope stability. Much of the published information that is required by engineers in industry is not available because the relevant technical journals are not always at hand at the mine site.

(geotechnical consultant)

The Pit Slope Manual has no index. Perhaps a new chapter should be compiled referring important words and terms to the various chapters.

(nonferrous mine operator)

A manual on the subject of slope stability of practical value to the small operator is a very important factor for the future from our view point, because the large operator is well able to have his own expertise on staff.

(mine inspector)

The manual should be extended to such topics as bank preparation for continuous mining and blasting near ultimate high walls, to meet the needs of strip coal mines and tar sands operations.

(university-based mining engineer)

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[52] Also see comments on coal mining, 'Benefit Barriers', appendix VI; and 'Summary of Responses to Questionnaire by Canadian National Committee on Rock Mechanics', earlier in this appendix.

The *Pit Slope Manual* should be updated with something like a yearbook, summarizing the major changes in technology which have taken place, including a bibliography, and reprints of significant papers.
(nonferrous mine operator)

The CANMET manual is useful because it is site-specific and has a broad input. All chapters of the manual require updating.
(nonferrous mine operator)

The manual is too complex, especially the design chapter and the computer packages. These should be simplified and more case studies added.
(nonferrous mine operator)

We were engaged under contract to CANMET to revise the monitoring chapter of the *Pit Slope Manual*. For reasons unknown to us, this revised chapter was never published, although I think it was generally agreed that the first published version was deficient in many respects. We are unaware of the deficiencies in the revised version except, perhaps, that additional case histories could usefully be added.
(geotechnical consultant)

We do not use the CANMET manual heavily, and probably less with time. The manual is a useful way to transfer technology to the mining industry. Periodic review of each chapter should be performed by respected professionals in their fields to verify that chapters remain at the present state-of-the-art practice in industry.
(geotechnical consultant)

We would like to see more case histories in the manual with the following format: definition of problem, required input, step-by-step solution.
(nonferrous mine operator)

The *Pit Slope Manual* is well worth keeping and updating. Formation of user groups is required to update the computer software, technology, etc, continuously. They should cooperate to advance the technology.
(university-based civil engineer)

I think that any manual should be updated every five years. There should be a standing committee for the revision of the manual and its eventual republishing.

(university-based civil engineer)

In updating and improving the CANMET manual, emphasis should be on more observational-oriented detection systems, and evaluation of the consequences of failure. It needs application to many case histories. This is the single biggest service that can be provided for all geotechnical engineers.

(geotechnical consultant)

We believe that the summary, groundwater, and design chapters are specifically in need of further development and updating, but in general most chapters would benefit greatly from a review.

(geotechnical consultant)

There have been significant advances in analysis and design methods in recent years. Hence, some of the material on analysis in the Pit Slope Manual may be dated. I feel additional research and general updating of the analysis sections of the manual, particularly in areas of toppling failure, multiplane failure and rock mass failure would be beneficial.

(geotechnical consultant)

The Pit Slope Manual at the time it came out in 1976 was 10 years ahead of practice. The gap has narrowed but the manual is still ahead of mining industry practice.

(university-based civil engineer)

It would be worthwhile to apply the CANMET manual further to coal. However, its present drawback is that it does not consider the type of failures encountered in bedded deposits - buckling, toppling, etc.

(geotechnical consultant)

The Pit Slope Manual reflects emphasis on Canadian mining. The next thrust should be into coal, since previously it was hard rock mining. There is a need for a similar manual for surface coal mines. There is also a need for case histories of pits, what angles they are using, and the documentation of failures.

(coal mine operator)

Further work is required on methods of detection prior to failure. Post-failure systems are well established now. The CANMET manual as it now stands is useful for very predictable structural geological problems.

(geotechncial consultant)

It was always our feeling that the pit slope project tended to diverge from practical applications in some of the research. We feel that if the manual were to be revised, emphasis could be directed towards providing a practical applications manual which could be used by the mining engineer in the field to help him solve his day-to-day problems by providing a large number of examples of problems and solutions. This might actually be a separate chapter entitled 'Case Histories of Pit Slope Design Problems and Documented Solutions'.

(geotechnical consultant)

TECHNOLOGY TRANSFER

The Pit Slope Manual is perhaps not as widely utilized as it might be with better and more extensive publicity.

(geotechnical consultant)

We became aware of the CANMET pit slope project through our involvement with CANMET in 1972. There was a definite need for the manual.

(nonferrous mine operator)

When faced with a potential slide, we consult the CANMET manual. The manual should be updated by adding new practical knowledge. Seminars are a good idea for transferring technology.

(nonferrous mine operator)

There was an important need for the CANMET project in the seventies when slope stability was still in an infancy stage. The CANMET manual is an excellent mechanism for transferring technology. Unfortunately, the manual is not entirely applicable to coal.

(mine inspector)

Our inspectorate became aware of the Pit Slope Manual from CANMET personnel while it was being compiled. During 1977, upon invitation to attend, two of our mines inspection engineers participated in a course at CANMET during which the manual was explained and discussed with potential users.

(mine inspector)

The Pit Slope Manual is a useful way to transfer technology to open pit mining practice. The manual is excellent and there is a definite need for it among non-specialist engineers. There is no substitute for it available today. The manual should be supported by seminars, training programs, etc. Without workshops, the manual is so voluminous that the mine operator does not know what the important points are.

(nonferrous mine operator)

The technology transfer effort soon dissipated largely because the chapter consultants and authors were not involved in the seminars. One of the feelings I heard expressed by a number was that CANMET simply wanted to take all the credit for the project.

(geotechnical consultant)

Our Department of Labour became aware of the manual directly from CANMET.

(mine inspector)

The Pit Slope Manual is used by us more often with time. No other reference comes close to it. The manual is an excellent way to transfer technology. We also use Rock Slope Engineering. The audio-visual package used at the 1976 CIM annual meeting was good but workshops should also be provided.

(geotechnical consultant)

The CANMET manual is a useful way to transfer technology but technical conferences with participants from selected areas of expertise could provide immediate impact.

(university-based mining engineer)

I believe that the major impact of the manual was during its development when many mines, engineers and consultants focused on the problem for several years and brought the importance of slope design to the fore.

(university-based mining engineer)

The Pit Slope Manual helps people who have no time for reading the current literature. However, it is my opinion that people in practice prefer intensive seminar courses with personal contact and training, in which they can ask the specialist to answer their questions directly.

(university-based mining engineer)

The purpose of the manual is to communicate an idea. The summary audio-visual package was excellent. However, the packages for the other chapters were terrible. The audio-visual show was edited for our ministry's use and employed to train inspectors and engineers. It is very dry, does not use professional voices, and is too detailed. Nevertheless, the audio-visual show is technically sound.

(mine inspector)

We have yet to see anyone from CANMET who would sit down with us and discuss ideas. The manual should be updated every couple of years.

(mine inspector)

I feel that the *Pit Slope Manual* is a valuable and viable way to transfer technology to open pit mining practice. However, I feel that the present manual probably suffered from budget cuts during its preparation period.

(geotechnical consultant)

On the whole I would say that the public relations image of the CANMET pit slope project is favourable and the only complaint might be that too few people in the United States know about it or know where to get a copy.

(university-based civil engineer)

I learned about the *Pit Slope Manual* through participation in a seminar convened by CANMET in Calgary during 1977. I presented a case study there on monitoring. I thought the seminar was an excellent way to transfer technology.

(nonferrous mine operator)

The *Pit Slope Manual* is well written and the diagrams are good. The use of the English language and proof reading are a credit to all the people concerned with the publications. The individual chapters of the manual are inexpensive, and easily obtained from a courteous and helpful staff. During the project, the arrangements for meetings in various parts of Canada were well handled, and the support staff were again courteous and helpful. This group are now experienced, have a proven record of success, and should be used again. As a set of reference books on pit slopes, the manual is acceptable and may have improved the standard of education being offered by some universities.

(nonferrous mine operator)

Courses and seminars are a good idea for technology transfer. However, a better way is to have a reference person for each chapter at CANMET that the mine operator can call to clarify a problem. If required, that person could visit the mine to discuss the problem. Also, rather than having the mine approach CANMET, why doesn't CANMET approach the mines to discuss problems? Personal contact is important. We need to try to break the division between CANMET and the mining industry.

(nonferrous mine operator)

I think it should be recognized that Don Coates made a major contribution of effort and resources, as well as personal intensity, to the project. A lot of the impetus of the project may have been lost when Don became ill and, hence, this may be part of the reason that the technology transfer phase did not last as long as anticipated.

(geotechnical consultant)

CANMET personnel were directly involved in providing advice to our operation in 1975 concerning the application of 'probability of failure' analysis. This made an important contribution to producing a well engineered pit design from a safety point of view.

(nonferrous mine operator)

A more efficient way to transfer technology is through the sale of well documented and designed computer programs. In order to pay for design and documentation, the sale price should be substantial.

(open pit supplier)

The CANMET manual is a useful way to transfer technology by exposing the mines to current data whereby they can either hire or train suitable individuals or proceed via a consultant to solve stability problems.

(mine inspector)

In my opinion, the indirect impact of the pit slope project on mining and rock mechanics engineering methods in Canada has been considerable. By indirect, I mean the diffusion of engineering knowledge which occurred at the actual time of investigation. The impact of the published manual has, unfortunately, been somewhat less. To some extent, this may be due to the simplification which occurred between the original investigators' reports and the writeups presented in the Pit Slope Manual itself. The greatest impact of the manual per se has, in my opinion, been with the mining companies themselves and has in some instances resulted in a considerable upgrading of technology.

(geotechnical consultant)

The technology transfer phase, if reactivated, could consist of two- to five-day seminars which could be given in key mining centres. In this way, a number of mines could send personnel at reasonable costs, thereby reducing seminar costs.

(geotechnical consultant)

We became aware of the CANMET manual in 1978 when CANMET made a slide presentation at our mine. It is an excellent manual. The technology could not have been transferred more quickly or effectively.

(asbestos mine operator)

The CANMET manual is not sufficient in itself but it serves as a good supplement. There is future potential for its use and, thus, it should be updated every five years. There should be a reference person at CANMET to contact if one has a problem.

(iron ore mine operator)

My opinion is that the Pit Slope Manual is a very useful way of transferring technology.

(geotechnical consultant)

Any future government research on slope stability would be overkill. Emphasis should be placed on improving the audio-visual packages, and follow-up with more seminars. There is need for a technology transfer group whereby open pit operations with slope stability problems can refer to someone specialized in the technology.

(mine inspector)

I do think that the Pit Slope Manual is a useful way to transfer technology to rock slope design and open pit mining practice. The primary educational role and the consciousness-raising probably occurs during the execution of research and development by the cooperative action of industry, government, universities and consultants which takes place before a single page of the manual is published.

(university-based mining engineer)

Our operation was involved in the CANMET project in 1972-73. Management became aware of slope stability after this first involvement.

(nonferrous mine operator)

The workshops that were put on were handled by CANMET staff, the majority of whom had very little experience in practical aspects of the mining projects themselves. In my opinion, the quality of the seminars were seriously lacking. A more important aspect, however, was that the mining industry did not trust the government and, thus, there was a lack of interest in the overall CANMET program. It would have been far better to have had the chapter authors present and take part in the seminars themselves. They would have been far more knowledgeable about the application of the research in each of the studies, and the seminars would have been far better received.

(geotechnical consultant)

GENERAL

Canada has done a poor job in mineral research and development and, in turn, CANMET has done a poor job. The Australian Mining Industry Research Association (AMIRA) has done some excellent research. Their mode of operation is to match up an applied research problem and funding from an interested group of mining companies with an appropriate research team. The team is funded for that particular project and disbanded when finished. The South African Chamber of Mines is another good example. In these cases the initiative and funding comes from the mining industry, rather than from the government as in Canada and the United States.

(geotechnical consultant)

Perhaps the best method of encouraging practical mining industry input in any future project would be to allow tax deductions for work approved by the CANMET director and his committee, with the government support staff responsible for publication. The mining companies would engage the consultants and universities of their choice to help with the work. The tax rebate would be paid in stages as the project work was completed, final payment being made when the director and committee were satisfied with the work and the written reports.

(nonferrous mine operator)

I believe the major improvement in technology transfer to open pit design procedure should be vested in university courses at undergraduate level as well as post graduate level. A further important contribution could be made if the CANMET project were to identify a responsibility structure for mines in which the technical department assumed direct production responsibility. Only in this way will technical development in mines move away from 'boffin' tag with which it is labelled today.

(geotechnical consultant)

An excellent text Underground Excavations in Rock by Hoek and Brown has recently been published. If an 'underground project' is going to be undertaken by the government, it would seem sensible to use avaliable work such as this book as a starting point. This would avoid the duplication of effort which occurred after Rock Slope Engineering was published by Hoek and Bray in 1974. The major shortcoming of the new Hoek and Brown underground book is the lack of detailed case histories and practical solutions, which would be supplied by the mining industry as part of any new project.

(nonferrous mine operator)

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